AN ELEMENTARY COURSE OF GEOLOGY, MINERALOGY, AND PHYSICAL GEOGRAPHY.

AN ELEMENTARY COURSE OF GEOLOGY, MINERALOGY, AND PHYSICAL GEOGRAPHY.

BY

DAVID T. ANSTED, M.A., F.R.S., ETC.

PROFESSOR OF GEOLOGY IN KING'S COLLEGE, LONDON,
LECTURER ON MINERALOGY AND GEOLOGY AT THE H. E. I. C. MIL. SEM. AT ADDISCOMBE,
AND AT THE PUTNEY COLLEGE,
LATE FELLOW OF JESUS COLLEGE, CAMBRIDGE.

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PREFACE.

In presenting this work to the Public, the Author thinks it right to offer a few explanatory remarks, stating the reasons that have induced him to prepare a second elementary treatise on Geology, and mentioning also the special object of the present volume. The first edition of his "Geology, Introductory, Descriptive, and Practical" (2 vols. 8vo.), published in 1844, was intended to supply the want which he believed to exist at that time of a descriptive account of the science and a statement of its practical bearings. The rapid demand for, and favourable reception of, that book, seemed to show that he had not judged amiss, but he has since been so frequently asked to recommend smaller manuals of Geology, Mineralogy, and Practical Geology, and the educational use of these departments of science has advanced so rapidly and steadily, that he believes a second edition of his former book would not really supply the present demand, and he has long had it in contemplation to prepare for educational purposes, for travellers, and for those who are endeavouring to cultivate knowledge on subjects connected with Geology, an outline which should be elementary, and, at the same time, tolerably complete, at least in some departments. He has been anxious also that the cost of the book should be such as to place it within the reach of all students.

In preparing, however, an Elementary course of instruction on Physical Geography, Mineralogy, and Geology, the Author has thought it best to begin at the very threshold of science, and explain the fundamental laws by which all changes are effected. He has enlarged much more on Physical Geography than in his former works, treating it now as a special subject; and has introduced an entirely new division—endeavouring to give a useful account of the

materials of the earth, as well as of the arrangement of rocks. The first 250 pages of the volume thus relate to subjects which are barely mentioned in his former book. In Descriptive Geology also he has dwelt much on the structure and composition of rocks, and but little on fossils — partly, because he believes the former subject both more neglected and more practically useful than the latter, and partly because he was unwilling to repeat what he has already elsewhere published at some length. The remainder of the Descriptive Geology, and the chapters on Practical Geology, are, for the most part, adapted and abridged from the work already alluded to, but the matter is re-arranged, and some very important portions are altogether new. These, again, have chiefly a practical tendency.

The Author has endeavoured throughout to avoid unnecessary discussion and confine himself strictly to facts. He has not failed to avail himself of such means of information as were at his disposal, and, amongst other works, has to confess great obligations to Johnston's (Berghaus') "Physical Atlas," the recent works of Humboldt, and the publications of Sir C. Lyell, in the first division; — to the treatises on Mineralogy by M. Dufresnoy, and Mr. Dana, in the second division; — and to Macculloch's "Treatise on Rocks," the "Memoirs of the Geological Survey of Great Britain," and Mr. R. C. Taylor's valuable work on the "Statistics of Coal," in the descriptive and practical divisions of his subject.

The illustrations in this volume are, with the exception of some diagrams, selected from Beudant's "Cours Elémentaire de Géologie," and the mineralogical part of Regnault's "Chimie." They are printed from casts obtained from the publisher of those works.

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ERRATA.

The READER is requested to correct the following important errors:—

In page 28, line 6 from top, *for* 126,720,000,000,000, *read* 1,267,200,000,000,000.
" 473, " 17, insert after "England" "north of the Wealden anticlinal."

Beyond this point, positive knowledge has not extended; and theoretical views, drawn from observations at the surface, however interesting and useful they may be, are not essential in the study of Mineralogy and Geology. On the other hand, the facts themselves, on which these sciences are based, are of the highest interest, and also possess direct practical value; and the main object in the following pages will be to place before the student observations that have been made and results immediately deduced from them. These will include an account *first*, of the condition of matter at the earth's surface, and the changes that take place there by the action of the various forces of gravitation and cohesion, heat, light, electricity, and magnetism; *secondly*, of the materials of which the surface is made up, and their ordinary combinations; *thirdly*, of the order of arrangement of the inorganic materials; *fourthly*, of the remains of organic

AN

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OF

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1. THE world on which we live is made known to us by various investigations, which all have reference either to the actual surface, or to such moderate depths beneath the surface as are laid bare by the ordinary operations of human ingenuity and labour. These have not yet reached so far as either to verify or contradict speculations often entertained concerning the condition of the great mass of the interior; so that we should be in total ignorance of this condition if it were not that, from the calculations of astronomers as to the earth's mass, we really know its average density, which appears to be about twice as great as that of the average density of the solid matter which forms the mass of the external surface. Beyond this point, positive knowledge has not extended; and theoretical views, drawn from observations at the surface, however interesting and useful they may be, are not essential in the study of Mineralogy and Geology. On the other hand, the facts themselves, on which these sciences are based, are of the highest interest, and also possess direct practical value; and the main object in the following pages will be to place before the student observations that have been made and results immediately deduced from them. These will include an account *first*, of the condition of matter at the earth's surface, and the changes that take place there by the action of the various forces of gravitation and cohesion, heat, light, electricity, and magnetism; *secondly*, of the materials of which the surface is made up, and their ordinary combinations; *thirdly*, of the order of arrangement of the inorganic materials; *fourthly*, of the remains of organic

bodies, contained in and associated with these inorganic materials; and *fifthly*, of the practical conclusions deduced from this kind of knowledge in reference to agriculture, architecture, civil and military engineering, and mining. These five departments may be designated respectively as Physical Geography, Mineralogy, Descriptive Geology, Palæontology, and Practical or Economic Geology.

2. Several terms have been, from time to time, introduced into modern languages from the Greek, to designate descriptions and histories of the earth. Of these, GEOGRAPHY (from *gē*, the earth, and *graphia*, an account), and GEOLOGY (*gē*, and *logos*, a discourse), both mean in strictness the same thing, but they have been received into the language with different senses; the former word, Geography, being understood to include an account of the surface, and that chiefly in its adaptation to civilised man; while the latter is understood to extend to the structure of the surface.*

So, again, both Geography and Geology have been considered under various and distinct points of view, according to the taste, the knowledge, or the immediate object of different writers; and terms, such as "physical," "descriptive," and "practical" have been applied to important divisions of each, while other not less important, if less manifest, portions have been marked off as distinct sciences, and have been called METEOROLOGY, HYDROLOGY, MINERALOGY, PALÆONTOLOGY, &c.

3. Without either lamenting the division thus produced in a department of science essentially one, or rejoicing at the causes which have introduced a multitude of labourers into this fertile field of observation, we will here rather discuss what has been done, and what may be done, in the way of connecting and bringing to bear upon each other the multitude of important facts of Physical Geography and Geology, which every one ought to know, but which many—otherwise well-informed persons—have greatly neglected. The earth on which we live has too great an influence on ourselves, directly and indirectly, to justify ignorance on the subject of its nature and constitution, or the laws which govern its material existence. The history of the present is too nearly connected with, and too di-

* A third term GEOGNOSY (from *ge* the earth, and *gnósis* knowledge), has also been introduced by the Germans, and was used by early writers in our own country. It is understood to mean the historical as distinct from the declaratory or descriptive part of the earth's history (Bischof's "Geologie"). This term is not likely to be referred to in modern geological works written in the English tongue, but occurs sometimes in translations from the German, when the translator deems it advisable to retain the technical meaning of the original, although at the risk of being imperfectly understood by the English reader.

rectly derived from, the events of the past to allow us safely to neglect it; and the mode of arrangement of the materials of which the outer film of matter, sometimes called "the earth's crust," is composed, too deeply involves the question of the daily and yearly change that takes place in what we see about us, to permit with safety any indifference in the comparison of results, often hardly to be distinguished except in degree, and in the probable date of their occurrence.

In all these matters the investigations concerning the earth's history, which are most generally understood by the term Geology, are found to be very interesting and important in a general sense, and affording much useful information; but, perhaps, it may be well, before proceeding further, that we should consider briefly the various applications of such knowledge to useful practical purposes, and in various employments and professions.

4. There are two ways in which this application may be made; namely, with regard to the actual surface of the earth and its dependence on that which happens to be beneath the surface, and also with reference to mineral substances which it is desired to obtain by various operations at the surface. Each is worthy of a few words of explanation.

If in any district we know the Geography, commonly so called, the political divisions, the natural divisions, the physical features, the relations of the hills, mountains, plains, and valleys, the rivers and river systems, the lakes, and the coast, yet still there remains a very important kind of information to be supplied before we can be said to know the country and its capabilities. We must know its structure before we can judge of its future agricultural value, both for soil and drainage; we have yet to learn the probability, or otherwise, of springs of water being obtainable, the future salubrity of the climate, the material that is at hand to be used for buildings of all kinds, the permanency of existing conditions, especially if near the sea, and the possibility of constructing great works, whether inland or on a coast, with any chance of their stability. We are also ignorant of the mineral riches of the district in metalliferous ores; for, to comprehend all these and many similar matters, we require a knowledge of that which is beneath the surface and the arrangement of the materials; since the soil is derived from the underlying rock, which also must be operated on in all architectural and engineering operations.

So, again, in the construction of roads, and in many other public works, where stone is needed for rough purposes, it may happen that there is abundance of excellent material in the immediate vicinity, not directly observable at the surface, but cropping out at a distance, and thus indicated to the eye of one acquainted with the general laws of the earth's structure. Without such knowledge, no one could suggest where this material would be continued underground, but with it the merest tyro could determine the spot where, by removing some accumulation of soil and detritus, the rock exists. The time must come when the value of such knowledge will be fully recognised, and when it will be regarded as essential as the practice of surveying to the profession of an engineer, and perhaps more useful to the colonist than any other information he can possibly acquire.

But if a knowledge of the earth's structure is of use in operations of this kind, what shall we say with regard to mining, where everything depends on what we know of the earth's itnerior, and where both general and local information of the usual condition and arrangement of rocks is essential. The whole subject of practical mining is, indeed, so immediately and directly dependent on structure, that nothing more can be necessary than to mention the fact.

Thus it appears, that in agriculture, architecture, engineering of all kinds, and mining, an acquaintance with the arrangement of the materials of the earth's crust, or, in other words, with GEOLOGY, ought to be combined with, and form part of, that special instruction which is needed by all who are called upon to act in any of those branches of practical and applied science. The results of geological knowledge are hardly less interesting to the astronomer, the zoologist, and the botanist; but these applications do not properly come within the object of the present work.

Geology treats of the materials themselves, of which the earth is composed, as well as the mode of their arrangement, but the former part of the subject is usually called MINERALOGY. The elementary discussion as to the laws governing the ultimate particles of matter is a part of CHEMISTRY, and the facts known concerning the general distribution of matter at the surface belong to the science of PHYSICAL GEOGRAPHY.

PART I.

PHYSICAL GEOGRAPHY.

CHAPTER I.

OF MATTER IN GENERAL, AND ESPECIALLY OF THE MECHANICAL CONDITION AND CHIEF PROPERTIES OF THE SUBSTANCES COMMONLY MET WITH NEAR THE EARTH'S SURFACE.

5. THE material substances of which the earth is composed are regarded either as simple or compound bodies, the former term including such as have never yet been proved to consist of more than one kind of substance, and the latter those which the operations of the chemist have shown to be made up of more than one.

It is evident that future investigations of chemists may either increase or diminish the list of simple substances or elements, since the decomposition of many now so recognised may depend on processes not yet discovered or applied. On the other hand, the number of possible compound bodies must be indefinite, although the actual combinations entered into in nature are so limited in various ways, that a list of what are called "simple minerals," or proximate elements, found in nature, is by no means very extensive, when we consider the large number of elementary substances (sixty-one) admitted in the present state of chemical knowledge. (See § 10.)

The supposed ultimate particles of bodies are called *molecules* or *atoms*, and must be extremely minute. Whether the molecules of certain compound bodies assume a special and quasi-elementary form remains still doubtful, although facts observed by mineralogical chemists render this not improbable; but it is at any rate certain, that the separation of particles may have effect to a very great extent, without destroying the affinity between certain substances. In other words, the tendency to combine together in the atoms of the same elementary substance is sometimes less powerful than is observed with regard to certain compound bodies.

Opinions have been entertained as to the possibility of the various elementary substances being themselves but different combinations of one ultimate atom, and speculations have been made as to the form which the ultimate or atoms may assume. The spherical is that form that seems at first to suggest itself, and, being the simplest, has been generally assumed.

Another speculation may be alluded to concerning the degree of divisibility of matter, and thus of the dimensions of the ultimate atom. Some of the metals are known to be reducible to an extremely minute state of division ; and, *argumentatively*, matter may apparently be proved to be infinitely divisible. These, however, are matters in which argument can have little value, and facts are extremely difficult to obtain.

6. Matter is presented to our notice in three different conditions, the solid, fluid, and gaseous. Some substances may readily be obtained in either of these states, as water, which is usually fluid, but in winter becomes solid, and when the pressure of the air is removed, passes into steam at a very small increase of ordinary temperature.

Many other substances, as, for instance, the common metals, are solid under ordinary circumstances, but may, by the aid of heat, be melted, although they can hardly be actually converted into vapour. Others are gaseous at the earth's surface under all common conditions, but can, by cold and great pressure, be converted into liquids, and many of them even into solids, while others again are far more refractory, and will scarcely undergo change without the most violent means, and under the most careful management.

We are thus led to expect that every substance in nature is really susceptible of the three states above-mentioned, if we could obtain favourable conditions of temperature and pressure. There is, however, apparently a limit to this, since a large number of solids become decomposed or separated into their elements under the action of heat, before they pass into the fluid, much less the gaseous state. This is the case with the common mineral, carbonate of lime (limestone), which parts with its carbonic acid before fusion. In this case, however, and perhaps in others, the decomposition may be prevented if the mineral is confined, and hermetically sealed within a very strong vessel.

7. Although we know nothing of the absolute weight of the ultimate atoms of different elements, it is perfectly possible, and very useful, to determine their relative weight, by assuming unity, or some number, to represent what is called the *atomic weight* of any one, and then by actual observation find the relative weight of the atoms of other bodies, according to the proportions by weight in which they combine. Thus, assuming the weight of hydrogen, the lightest known substance, to be unity, or 1, we find that of oxygen to be 8, for water being always composed of an equal number of atoms of hydrogen and oxygen gas (which appears from experiment), the weight of the atom of the latter must be eight times that of the former, since 100 grains of water contain 11·1

grains of hydrogen and 88·9 grains of oxygen. The theory thus involved, that bodies combine only in quantities of this kind, or in multiples of them, is a representation of the actual law of combination, and only introduces a more convenient way of speaking of the known combining proportions of various substances. That there are combining proportions is a simple and well-assured fact, and every observation and investigation of modern analytical chemists proves its universality, so that in fact it forms the basis of all accurate knowledge in chemistry and mineralogy.

8. The gaseous elements, and other bodies in a gaseous state, always combine in proportionate measures of size, or *volume*, as well as weight; and the volume is more easily determined, and more convenient, than the weight. Thus, while water consists of one atom of hydrogen to each atom of oxygen, and while in each hundred parts of water by weight 11·1 parts are hydrogen and 88·9 parts oxygen, there are two volumes of hydrogen for each one of oxygen; and not only so, but in every case hydrogen enters into combination in double volumes. There is, therefore, a *combining measure* as well as an atomic weight of the elements to be considered, if we would comprehend the true nature of combination.*

9. Combinations are generally expressed by a particular termination, the exact meaning of which it is essential that the student should be acquainted with. Thus when one body combines with another, the termination *-ide* or *-uret* is added to that one which is considered to qualify or modify the other, which is then called the base. Thus we have combinations of oxygen with one other element called *oxides*, and also the following:—

From	Chlorine	are obtained	chlorides.
„	Bromine	„ „	bromides.
„	Iodine	„ „	iodides.
„	Fluorine	„ „	fluorides.

And again:—

From	Sulphur	are obtained	sulphurets.
„	Carbon	„ „	carburets.
„	Phosphorus	„ „	phosphurets.

Sometimes, however, we read in chemical books of *sulphides* and sometimes of *chlorurets*, but such expressions are synonyms, and rarely used.

The binary compounds of oxygen which possess acid properties, are named on a different principle. Thus the acid produced by the combination of sulphur with oxygen is called *sulphuric*, *hyposulphuric*, *sulphurous*, or *hyposulphurous acid*, according as the proportion of oxygen is more or less considerable. This illustration will serve to explain the system; and, although other terms have been introduced, they will not come before us in speaking of simple minerals.

Compounds of the second order are combinations of an acid or binary compound with some element as a base, and they are called, as a group, *salts*. They are named according to the acid they contain, the termination *-ic* being changed to *-ate*, and *-ous* to *-ite*. Thus from carbonic acid and copper is formed *carbonate of copper*.

Combinations of water with other oxides are called *hydrates*.

In the case of double salts the acid is only mentioned once, though it applies to

* The following are the combining measures of some elements. Oxygen *one*, hydrogen *two*, nitrogen *two*, chlorine *two*, fluorine *two*, phosphorus *one*, carbon *two*, silicon *two*, sulphur *one*, bromine *two*, iodine *two*.

both bases. Thus alum is a sulphate of alumina combined with a sulphate of potash, but is called simply a *sulphate of alumina and potash.*

In speaking of combinations, and using certain symbols, which are generally the initial letters of the elements, both the chemist and mineralogist find it convenient to understand by the symbol *one equivalent by weight* of the element, or, in other words, the quantity by weight in which it combines. Thus, O signifies one equivalent of oxygen, H one equivalent of hydrogen, and HO together the combination of one equivalent of oxygen with one of hydrogen or water. So, again, O_2 signifies two equivalents of oxygen, and so on ; and thus, as S signifies sulphur, and three equivalents of oxygen with one of sulphur form sulphuric acid, SO_3 is the symbol of sulphuric acid. So a double salt may be thus expressed, KO,SO_3; where K, signifying the metal potassium, KO is oxide of potassium or potash, and SO_3 sulphuric acid, and thus the above symbol expresses *sulphate of potash.* It is of great importance to understand these chemical formulæ, if the student would become acquainted with the important facts of mineralogy and geology.

10. We now give a list of the elementary substances, with their symbols, their equivalents, and in a few cases, their important and most frequent combinations. The number tabulated is only fifty-one; but in addition to them are the following, hitherto only known to the chemist :—Didymium, Erbium, Lanthanum, Niobium, Pelopium, Ruthenium, Terbium, Thorium, and two others still doubtful, Ilmenium and Norium.

TABLE

OF

THE PRINCIPAL ELEMENTARY SUBSTANCES,

WITH THEIR CHEMICAL EQUIVALENTS.*

SYMBOLS.	ELEMENTS.	EQUIVALENTS.		COMMON COMBINATION.
		H=1	O=100	
	Gaseous Bodies.			
Cl.	†CHLORINE	35·50	443·75	
F.	Fluorine	18·70	233·80	
H.	HYDROGEN	1·00	12·50	HO Water.
N.	†NITROGEN	14·00	175·00	NO_5 Nitric acid. NH_3 Ammonia.
O.	†OXYGEN	8·00	100·00	
	Fluid (non-metallic).			
Br.	Bromine	78·26	978·30	
	Non-metallic Solids.			
B.	Boron	10·90	136·20	BO_3 Boracic acid.
C.	†CARBON	6·00	75·00	CO_2 Carbonic acid
I.	Iodine	126·36	1579·50	
Ph.	PHOSPHORUS	32·02	400·30	
Se.	Selenium	39·57	494·58	
Si.	†SILICON	21·35	266·82	SiO_3 Silica.
S.	†SULPHUR	16·00	200·00	SO_3 Sulphuric acid.

* The table is adapted from Graham's Elements of Chemistry, second edition, p. 108.

SYMBOLS.	ELEMENTS.	EQUIVALENTS. H=1	EQUIVALENTS. O=100	COMMON COMBINATION.
	Metallic Bases of Alkalies.			
Li.	Lithium	6·43	80·37	
K.	†Potassium (Kalium)	39·00	487·50	KO Potash.
Na.	†Sodium (Natronium)	22·97	287·17	NaO Soda.
	Metallic Bases of Alkaline Earths.			
Ba.	Barium	68·64	858·01	BaO Baryta.
Ca.	†Calcium	20·00	250·00	CaO Lime.
Mg.	Magnesium	12·67	158·35	MgO Magnesia.
Sr.	Strontium	43·84	548·02	SrO Strontium.
	Metallic Bases of Earths Proper.			
Al.	†Aluminum	13·69	171·17	A_2O_3 Alumina.
Gl.	Glucinum	26·50	331·26	Gl_2O_3 Glucina.
Y.	Yttrium	32·20	402·51	YO Yttria.
Zr.	Zirconium	33·62	420·20	Zr_2O_3 Zirconia.
	Metals proper.			
Sb	†Antimony (Stibium)	129·03	1612·90	Sb_2S_3 Sulphuret of Antimony.
As	†Arsenic	75·00	937·50	
Bi	†Bismuth	70·95	886·92	
Cd.	Cadmium	55·74	696·77	
Ce.	Cerium	46·00	575·00	
Cr	Chromium	28·15	351·82	
Co	Cobalt	29·52	368·99	$Co_8As_5 + 8HO$. Cobalt bloom.
Cu.	†Copper (Cuprum)	31·66	395·70	Cu_2S. Copper pyrites. $2CuC+HO$. Malachite.
Au.	†Gold (Aurum)	98·33	1229·16	
Ir	Iridium	98·68	1233·50	
Fe	†Iron (Ferrum)	28·00	350·00	FeO,CO_2. Spathic iron. $Fe\ S_2$. Iron pyrites.
Pb.	Lead (Plumbum)	103·56	1294·50	PbS. Galena.
Mn.	Manganese	27·67	345·90	MnO_2+HO. Wad.
Hg.	Mercury (Hydrargyrum)	100·07	1250·90	HgS. Cinnabar.
Mb.	Molybdenum	47·88	598·52	MbS_2. Sulphuret of Molybdenum.
Ni	Nickel	29·57	369·68	NiS. Capillary pyrites.
Os.	Osmium	99·56	1244·49	
Pd	†Palladium	53·27	665·90	
Pt	†Platinum	98·68	1233·50	
R	Rhodium	52·11	651·39	
Ag	†Silver (Argentum)	108·00	1350·00	AgS. Vitreous Silver. $AgCl_2$. Horn Silver.
Ta	Tantalum (Columbium)	92·30	1153·72	
Te	†Tellurium	66·14	801·76	
Sn	Tin (Stannum)	58·82	735·29	SnO_2. Tin-stone.
Ti	Titanium	24·29	303·66	
W	Tungsten (Wolfram)	94·64	1183·00	
U	Uranium	60·00	750·00	
V	Vanadium	68·55	856·89	
Zn	Zinc	32·52	406·59	ZnS. Blende. ZnC_2. Calamine.

A great number of these elements are exceedingly rare; others widely distributed, but only in extremely small quantities; and others again are not met with, except in combination. The names of those which require to be generally known, as being used in the arts or producing a marked effect in nature on a large scale, are printed in capitals in the above list, and those which occur in nature in their simple or *native* form, are marked with a little dagger (†).

11. All elementary substances are formed by the aggregation, or heaping together of the separate atoms of one element, and this is effected always in the same way for the same substance, when under similar conditions, so that the substance is always recognisable by the application of the same means. A perfect or chemical combination takes place only when one or more atoms of one substance arrange themselves in perfect symmetry by the side of one or more atoms of another substance or of several other substances, so as to form a complete compound atom, which afterwards is capable of accumulation like a simple atom. The association of atoms without the formation of compound atoms, is called *mixture*, and not *combination*. The former condition (that of mixture) is seen in the alloys of various metals, as of copper and zinc to form brass, &c.; and also in the mixture of oxygen with nitrogen gases existing in the atmosphere. Combination is seen in a vast multitude of common substances, of which water is the most widely extended and the most remarkable. In this state of combination, and as a proximate element, water, which is formed of oxygen and hydrogen gases, enters into the composition of almost all compound solids.

12. Upon the earth's surface, and within such moderate depths as can be penetrated by man, matter exists generally in a solid form, except in the case of water, which — though rarely to a depth of more than five or six miles—covers three-fourths of the surface; and the atmosphere, which invests the whole globe with an aerial veil, reaching seventy, or even a hundred miles, above the mean level of the surface, but gradually becoming more rare, and its particles more widely separated in consequence of its elasticity. But the atmosphere and water, although almost their whole substance is made up of gaseous elements (or substances, which when uncompounded, retain the aerial condition at the earth's surface), form only a small proportion of the whole amount of such elements, for probably not less than one-half of all solid rocks consists of OXYGEN GAS, which is thus the most common and abundant of all substances and one whose properties and influence should never be lost sight of.

HYDROGEN and NITROGEN gases are next in importance to Oxygen as materials of the crust, or external film of the earth. The former is not only the chief constituent of water, but is also present in large quantities in mineral fuel of all kinds, and in most minerals.

Nitrogen forms four-fifths of the atmosphere, and is widely distributed amongst many solids. CHLORINE also is abundantly present, as well in sea-salt as in other combinations.

13. Of the non-metallic elements, CARBON is the most abundant, existing in all limestones and rocks containing calcareous matter, besides forming the chief constituent of coal. SULPHUR is found in combination with a large number of metals in their most common form, and occurs native in volcanoes. SILICON, the base of common flint, sandstone, and siliceous rock of all kinds, may be considered as forming, on an average, one-half of all those rocks commonly met with at the earth's surface, with the exception of limestones. PHOSPHORUS and IODINE have been found in almost all rocks.

14. Of the metallic bases of earth, ALUMINUM is probably the most abundant; forming the characteristic part of all clays, besides being present in almost all other rocks. POTASSIUM, SODIUM, and MAGNESIUM, the metallic bases whence are derived the salts of potash, soda and magnesia, are also very widely disseminated, the two former abounding especially in volcanic rocks of all ages, while soda is the chief ingredient of common salt, and magnesia, besides forming an important part of some rocks, is present in sea water.

CALCIUM, from the combination of which with oxygen is produced lime, and whence therefore all limestones are derived, is a material of which very large quantities exist in the earth, although it is perhaps not so abundant as the other elements above alluded to.

Of the metals, commonly so called, IRON and MANGANESE are those most widely diffused, and the former has been calculated to form as much as 2 per cent of the whole mineral crust of the globe. There is scarcely a rock without them, and the same may be said of Gold, Arsenic, and Titanium, which however are present in infinitely smaller quantities than either of the others.

15. The mineral substances, then, which chiefly compose the mass of the earth, may be thus stated.

1. GASES (3), Oxygen, Hydrogen, Nitrogen.

2. NON-METALLIC SOLIDS (5), Silicon, Carbon, Sulphur, Phosphorus, Iodine.

3. METALLIC BASES OF EARTHS AND ALKALIES (5), Aluminum, Potassium, Sodium, Magnesium, Calcium.

4. METALS (5), Iron, Manganese, Gold, Titanium, Arsenic.

All these, and many others of great importance in the arts, will be considered at some length in a future chapter, when minerals are described. Their names are here given, chiefly to remind the student of the fact of their existence in sufficient abundance to influence various common and characteristic rocks.

CHAPTER II.

OF THE FORCES OF ATTRACTION AND REPULSION, AND OF LIGHT, HEAT, ELECTRICITY, AND CHEMICAL AFFINITY.

16. THERE are two great and opposing forces in nature, attraction and repulsion, or in other words there is a constant tendency in all matter to approach other matter, and a constant action of some force, of which heat is the most usual indication, tending to keep the particles of bodies asunder. It is necessary to consider here so much of chemistry as may serve to explain the action of these forces with reference to the general constitution of the earth's crust.

The forces of attraction are apparently three, namely, gravitation, cohesion, and chemical affinity, the latter, however, existing under very peculiar conditions, and presenting some anomalous cases. *Gravitation* is the name given to the attraction of masses of matter at some distance from each other. *Cohesion* is also attraction in mass, but at immeasurably small distances, while *Chemical affinity* is a somewhat similar kind of attraction acting, however, upon the molecules or ultimate atoms. There is only one conceivable force of repulsion, but it shows itself not alone by expansion, but also by impenetrability. Electricity as exhibited by the phenomena of galvanism and magnetism, as well as ordinary electrical action, belongs to a class of forces usually spoken of as *polar*.

17. *Gravitation* appears to affect all matter, not only on and in our earth, but throughout our solar system; and to reach even to the most distant of those bodies throughout the universe, recognisable either by the eye, or by their effect upon the course which our earth takes in space. By it every substance on the earth's surface presses down towards the earth's centre, and thus acquires what is called "weight," which is in direct proportion to the mass of matter contained in a given space, and by it also the earth is kept in its position with reference to the moon, the planets and the sun, and all other bodies in the universe. Acting, however, thus universally, and increasing rapidly as the distance between two bodies diminishes, still it does not appear that gravitation alone would be sufficient to produce that close contact on which chemical action depends, nor are the laws which seem to govern the former force altogether applicable in the latter case.

18. The force of *Cohesion* is that by which the similar molecules or atoms of a simple substance, or similar compound atoms are brought into aggregation, so as to form masses of matter, distinguishable from other masses, and having definite properties.

This force is very great in solids, small in liquids, and absolutely nothing in gases, where on the contrary the particles tend to separate from each other, and are only retained at any given distance by external pressure. Cohesion is seen in liquids by their tendency to assume a spherical form, and also by a certain resistance to the action of gravitation, since mercury will not run through fine muslin; but this cohesion being small and equal in all directions, the slightest force is sufficient to disturb and separate the particles. Different liquids exhibit different degrees of cohesion; the cohesive power being for the most part nearly proportional to the density.

The force of cohesion acting between different solid masses brought into close contact at many points is called *adhesion*, and is in some cases very considerable, though generally less in amount than would be found to exist between different parts of one substance. This kind of attraction effects no change in the properties of bodies, although, as in the case of cements of all kinds, it binds different kinds of matter together.

Its power is seen and well exemplified in the case of glass, especially when a number of plates, smooth and clean, are kept in close contact by pressure for a long time, as when this is done it is sometimes impossible to separate the plates without fracture. It is recognised also in all the ordinary phenomena of friction, and thus becomes of great practical importance, since adhesion takes place with different force under different circumstances, and between different substances in nature.

19. Certain bodies, when placed in contact, exhibit a tendency to mix with each other only to a limited extent, as when a certain quantity of common salt is dissolved in pure water; or they actually undergo mutual decomposition, as when limestone is placed in diluted sulphuric acid; while other substances, as water and alcohol, may be mixed most intimately without any change or limit. The cause of decomposition and recombination has been considered to be some specific attraction between different kinds of matter, which attraction has received the name of *Chemical affinity*, and as the affinity between different bodies not only differs very widely in intensity, but often exhibits itself in a kind of preference to combine with one body rather than another, it has been called *Elective affinity*, and many remarkable facts have been observed by chemists with reference to this subject. We proceed to explain shortly the meaning of these expressions.

Chemical combination takes place in various ways and under various circumstances, but chiefly, and most energetically, when one or both substances are in the gaseous or liquid state, for they are then at once brought into very immediate contact. It is also much assisted by heat, light, and electricity; and, indeed, the development

of one of these imponderable forces is a usual accompaniment of change in chemical combinations. The time required for the process varies greatly under different circumstances.

The proportions in which bodies combine are generally very definite; and this is more clearly seen as the affinity between the combining substances is greater. There are also, however, two kinds of mixture which are not regarded as true combinations; the first being like that of water and alcohol, any quantity of the one mixing with any quantity of the other; and the other, that of common salt with water, where a certain quantity, and no more, of the one, is received into and forms part of a given quantity of the other. When this quantity has been taken up, the one substance (the fluid) is said to be *saturated* with the other. The remaining and more definite cases include the whole range of true chemical compounds.

21. It will now be understood that *affinity* as used in chemistry has a very distinct and peculiar meaning. It is by no means *mere resemblance* in any sense of the term, for it is not that relation of parts or of a whole which only amounts to similarity; nor is it mechanical connection, or the attraction of gravitation, cohesion, or adhesion, as understood when discussing matters relating to physical science. It means the tendency of different kinds of matter to form distinct and definite compounds; and in this sense it is a peculiar force connected with almost all chemical changes and operations.

22. One of the most singular of the properties brought under consideration in investigating the nature of this affinity, is, that when several bodies, each of which is capable of combination with any of the others, are allowed to combine freely, there is a selection made, and this is always according to the same law and is generally very strongly marked, indicating not only a preference for one particular combination, but a long gradation of preferences, so that particular substances select out of a large number those with which under the circumstances they will unite, and a number of new compounds is the result. Not only is this the case when all the elements are free, but sometimes when two compounds already formed are presented to one another, though each one is capable of existing permanently. The affinity, therefore, that exists is truly *elective*, each element choosing or *electing* one rather than another of the elements presented to it, and quitting one to unite with another which it prefers.* This singular *elective affinity* having been proved

* Thus in dilute nitric acid we may dissolve silver, the nitric acid parting with its oxygen to the silver, which has a greater affinity for it than the nitrogen. If in this solution, however, we put in copper, the silver is released from combination, and the oxygen passes to the copper; if we put in iron, the copper goes down; if zinc, the iron is precipitated; if we put in ammonia, the zinc is separated, and if, lastly, we put in caustic potass, or soda, the ammonia also is liberated.

to exist for each element, tables have been formed expressing the order of affinities of each element for others.

There can be no doubt that processes of change dependent on elective affinities are constantly going on in the solid crust of the earth, and most distinctly in those crevices and fissures called mineral veins, in which the great majority of simple minerals exist. It behoves us, therefore, to bear in mind the true meaning and the extent of affinity, and its elective character, if we would understand the results presented on a grand scale in nature.

23. But affinity in chemistry is not only elective or definite as to *kind,* but also, and in a very remarkable way, as to *quantity,* for one element not only prefers to combine with another of a certain kind, but also to a certain extent and no further, so that the result is not accidental and variable, but fixed and constant.

This result, indeed, might have been anticipated from a due consideration of the positive and real qualities of certain compounds, for if every mere mixture was a chemical compound it is obvious that there would be nothing definite in nature; but it has also been found that although one ingredient will unite with another in different proportions, still in such cases these proportions are multiples one of another.

The law thus indicated includes not only the fact already known that elements combine in definite proportions, but also that the combining proportions are related as multiples, and in this form it is the foundation of what has been already mentioned as the *atomic theory* (see § 7); since if we suppose bodies to be composed of atoms of their constituent elements grouped either one and one, one and two, one and three, and so on, and sometimes two and three, two and five, &c., we shall perceive at once the nature of the limitation of elective affinity when various quantities of different substances are presented to one another. Whether we term the ultimate particles assumed, *atoms,* and speak of their atomic weight, or whether these atomic weights are called chemical equivalents or proportions, as has been suggested, the main result is the same; and we are able to represent all those definite compounds which possess a peculiar and distinctive character, and which alone, therefore, can be looked upon as individuals, by certain marks and numbers which belong to them, and them only, and have reference to their absolute and intimate structure.

24. Obeying the laws of elective and quantitative affinity, the number of actual combinations found in nature, to which any definite character can be attached, becomes greatly limited, and all known compounds may indeed be distributed into three orders; the first (binary compounds), including those where one element combines with another, as for instance oxygen with sulphur in sulphuric acid,

and sodium with oxygen in soda; the second (ternary compounds), those in which one binary compound combines with another, as sulphuric acid with soda in Glauber's salt. And, thirdly, there are combinations of salts with one another, or double salts (quaternary compounds), such as alum. We have already (in paragraph 9) explained the usual notation of chemists in this matter.

25. The agents of change in the ultimate particles of bodies are light, heat, and electricity; any one of these under certain circumstances placing the atoms in a condition favourable to chemical action, and apparently assisting certain compounds to become decomposed, and the elements to enter into new combinations. There is unquestionably a very strong analogy in the case of these three forces, although at present no proof exists of their absolute identity, and we shall here merely refer to their properties, so far as they have reference to changes in the constitution of mineral substances. Light and heat being very intimately related, especially in their joint derivation from the sun, it is not easy to dissociate their ideas and yet retain an appreciation of their actual influence on each other. Still we must endeavour to do this, and can best succeed by simply defining or stating the important distinctive properties of each.

26. White Light, proceeding from the sun, and reaching our earth, is made up of several colours, which are not all either reflected or transmitted to the same extent in all cases. The result is that certain objects exhibit to the eye coloured rays only, which are the mixed rays that result after the atmosphere and the object regarded have absorbed a part, which is the same under similar conditions, but which varies if the circumstances change. The light falling at one particular angle (35° for glass), or transmitted through a certain thickness of any medium, is found to possess very peculiar properties, and is said to be *polarized*, and a ray of light passing through certain substances, is divided into two pencils or rays.

Light is absorbed by all ponderable substances to some extent, when they are exposed to its influence, and the quantity absorbed is greater in proportion to the roughness of the surface. Those substances which present a dark colour to the eye, and through which light is not transmitted (opaque bodies), absorb most light, and those which are transparent, the least. The more light a body absorbs, the more is its temperature raised when exposed directly to the effect of the sun's rays, which produce heat as well as light. All bodies, when heated to a certain temperature, become incandescent and emit light. Light is also directly connected with electricity and magnetism, the passage of electricity being accompanied by the emission of light when the transmission through a conductor is broken, and light, under certain conditions, exciting magnetic action in a steel needle. A ray of polarized light passing

through certain transparent substances, is found to be directly affected, and altered in position, being rotated to the right or left hand by the passage of magnetic force through the medium, the direction of rotation being governed by the position of the lines of magnetic force.

Many substances are decomposed by the action of light, and often more readily by one colour than another. The remarkable and interesting processes of daguerreotype and calotype, or the production of pictures by the simple action of light, afford good examples of this chemical action. In some cases again chemical combinations are effected by exposure to light, and not unfrequently such combinations are accompanied by decompositions. Many, but not all, of the changes produced by light, may also be brought about by a trifling elevation of temperature, or slight electrical action, and many substances whose affinity for each other is considerable, develop light and heat at the moment of their combination. Other cases occur in which mechanical violence, friction, and crystallization are accompanied by an exhibition of light, often, but not always, connected with the presence of heat and electricity.

27. Heat, like light, is obtained from the sun's rays, and is also excited in various ways by mechanical violence, electricity, animal and vegetable life, and chemical combination. Rays of heat are reflected or thrown back from the surface, and refracted, or bent, in passing into a different medium, like rays of light, but heat is conducted along certain substances, and transmitted through others, more completely than light, and under different conditions.

Heat is, beyond all other forces, that which chiefly tends to separate the atoms, or component particles, of bodies from each other, and is always accompanied by changes of volume when brought to act on any substance. It is, therefore, eminently a force of repulsion, and by its agency gaseous bodies tend constantly to expand, liquids to become gases, and solids to become liquid, and afterwards gaseous.

Metals, and indeed all solids, expand when heated, but the amount is generally small, and different in different substances. The increase is not uniform in all dimensions, as some crystalline bodies alter their form by changes of temperature, nor is it invariably the case throughout nature that an addition of temperature produces expansion; water offering a remarkable exception among fluids, and a compound of one half by weight of bismuth with one fourth part of lead and one of tin presenting a similar incongruity in solids. The case of water is, however, the most remarkable, and is of very great importance, as upon it depend many striking results in the general economy of nature. The temperature at which water is most dense is 39·2° Fahr.; while that at which it freezes, or passes

into the solid state, is well known to be 32° Fahr.: so that, in cooling down from 39°, water expands before solidifying. One result of this is, that ice is lighter than water, and floats on its surface instead of sinking. Another, of no less importance, is the great change effected by the alternate elevations and depressions of temperature that take place in many parts of the world on each side of the point of greatest density, and the corresponding expansions and contractions, especially in mountain districts.

Heat is developed during all chemical change, as well as by percussion, friction, and other mechanical violence, and by the passage of an electric current. The action of heat alone is, in many cases, sufficient to produce decomposition, this being the case with water when the experiment is conducted with great care; and probably, at some temperature or other, the attraction of affinity tending to form a definite chemical compound would be completely overcome in every case, and the elementary state of the component parts attained.

28. The phenomena generally described as due to electricity, galvanism, and magnetism, appear to be only various forms in which one peculiar force exhibits its action. Magnetism is that form which is best known and easiest to appreciate on a small scale, because iron and some of its oxides and alloys exhibit attraction and repulsion very distinctly and powerfully, and show a tendency in the metal, when in the form of a needle or bar, to place itself in a constant direction with reference to the poles of the earth, when freely suspended in space. This singular property has been employed now for a long time in the *mariner's compass,* as a means of ascertaining relative position on the earth's surface. It has been found of late years that other metals, as cobalt and nickel, partake of similar properties,* being attracted by the magnet and becoming magnetic; but, indeed, all matter is distinctly acted on, more or less powerfully, by this force, since those elements and compounds which cannot be made magnetic, or, in other words, which are not attracted by the magnet, and do not, when freely suspended in bars, arrange themselves parallel to the earth's axis (strictly speaking, one of the magnetic axes, as will be presently explained), are repelled by the magnet, and arrange themselves, if having the form of a bar, in what may be called an equatorial position, that is, in a plane at right angles to the straight line joining the two poles.† Of all

* The following is a list of the elements which are now recognised as magnetic; *viz.* iron, nickel, cobalt, manganese, chromium, cerium, titanium, palladium, platinum, osmium. Copper and zinc, also, although in a simple state belonging to the other class, are in certain states of combination magnetic bodies.

† This result, the recent discovery of Faraday, can only be obtained by the use of the most powerful magnets, and is, beyond doubt, the most important contribution physical science has received since the discoveries of Newton concerning the law of force in gravitation and the universality of the action of that force.

substances yet experimented on, bismuth is the most powerful of this latter kind (called *diamagnetic* bodies), and after it follow phosphorus, antimony, zinc, tin, cadmium, sodium, mercury, lead, silver, copper, gold, arsenic, uranium, rhodium, iridium, tungsten, which all tend to place themselves equatorially when undergoing the direct action of magnetic force. The crystalline condition of these bodies influences very greatly the direct action produced by magnetic force, but this will be considered more properly in a future paragraph.

29. If a piece of amber or sealing-wax is rubbed on cloth, it acquires the property of attracting light bodies, and the force of attraction thus excited is capable of extremely rapid transmission either through or upon the surface of certain substances, of which all the common metals are good examples. This force is called *Electricity.* It is diffused throughout all matter, and is constantly producing effects on the earth, since it is developed not merely by friction in the substances already named, but by every change in mechanical or chemical condition effected in those and all other substances in nature. It is best understood by regarding it as the result of a current proceeding from or through each material substance, or of some principle which is ever active in maintaining its equilibrium, and which, consequently must act in two directions. It may be called *a polar force.*

However we may define or limit particular exhibitions of polar force, and connect them with or separate them from other forms of force, such as that of gravitation, cohesion, or ordinary chemical agency, there is now no doubt of the mutual relations of all the most important of these, since light, heat, electricity, galvanism, and magnetism can all be made to bring about similar results, and tend to change the position and alter the association of every known form of matter, whether simple or compound.

30. The phenomena now recognised as those of terrestrial magnetism, and exhibited in various conditions and appearances of the atmosphere and clouds, have been attributed to currents of electricity circulating near the contact of air and earth at the surface of the solid matter of the globe. It has been supposed by some that these currents traverse our globe from east to west, and that in this way magnetic bodies take the direction of north and south, not from the terrestrial action of fixed magnetic poles, but from the repulsion of the currents; but another view of the case, an earlier theory, according to which were assumed two fluids, positive and negative, traversing all matter in opposite directions, and mutually attracting and repelling each other, has been considered more satisfactory in explaining the observed appearances.

If a magnetic bar or needle is freely suspended above the earth, it assumes a given direction and position, which is an indication of

the earth's magnetic force. This direction is not true north, except when the needle is suspended on one of two lines on the earth's surface, called *lines of no variation,* one in the eastern, the other in the western hemisphere. "The American line is singularly regular, passing in a south-easterly direction from north latitude 60° to the west of Hudson's Bay, across the American lakes, till it reaches the South Atlantic Ocean, and cutting the meridian of Greenwich in about 65° south latitude. The Asiatic line of no variation is very irregular, owing, no doubt, to local interferences; it begins below New Holland in south latitude 60°, bends westward across the Indian Ocean, and from Bombay has an inflexion eastward through China, and then northward across the Sea of Japan, till it reaches the latitude of 71° north, when it descends again southward with an immense semicircular bend, which terminates in the White Sea." *

There are two points in each hemisphere which have been regarded as stronger and weaker points of attraction on opposite sides of the earth's poles of revolution. These are the magnetic poles of the earth, and are considered to have a regular motion round the globe: the two northern ones from west to east, and the southern ones from east to west, so that the line of no variation is constantly shifting.†

31. "We have also remarkable variations in what is termed the *dip* of the needle. It is well known that a piece of unmagnetized steel, if carefully suspended by its centre, will swing in a perfectly horizontal position, but if we magnetize this bar it will immediately be drawn downwards at one end. The force of the earth's magnetism attracting the dissimilar pole has caused it to *dip.*

"There is in the neighbourhood of the earth's equator, and cutting it at four points, an irregular curve called the *magnetic equator* or *aclinic line,* where the needle balances itself horizontally. As we proceed from this line towards either pole the dip increases, until at the north and south poles the needle takes a vertical position. The *intensity* of the earth's magnetism is also found to vary with the position, and to increase in a proportion which corresponds very closely with the dip; but the *intensity* is not a function of the dip, and the lines of equal intensity, *isodynamic lines,* are not parallel to those of equal dip. We have already remarked on the diurnal variation of the declination of the needle; we know, also, that there exists a regular monthly and daily change in the magnetic intensity. The greatest monthly change appears when the earth is in its perihelion and aphelion in the months of December and June, at which

* Hunt's Poetry of Science, p. 211.

† This line passed through London during the years 1657 to 1662, when the needle consequently pointed true north. The variation commenced, and continued steadily increasing, after the latter year, the needle always pointing west of true north, till in 1815, it diverged as much as 24° 15′ 17″. Since that time it has been slowly diminishing, and now in London amounts to about 23°.

times a maximum occurs; and about the time of the equinoxes, when our planet is at the greatest mean distance from the sun, and a minimum is detected.

"The daily variation of intensity is greatest in the summer and least in the winter. The magnetism is generally found to be at a minimum when the sun is near the meridian, its intensity increasing until about six o'clock, when it again diminishes.

32. "All these well-ascertained facts give striking proof of the dependence of terrestrial magnetism on solar influence; and in further confirmation of this view, we find a very remarkable coincidence between the lines of equal temperature, the isothermal lines, and those of equal dip and magnetic intensity.

"Sir David Brewster first pointed out that there were in the northern hemisphere two poles of maximum cold; these poles agree with the magnetic points of convergence, and the line of maximum heat which does not run parallel to the earth's equator is nearly coincident with that of magnetic power. Since Seebeck has shown us that electrical and magneto-electrical phenomena can be produced by the action of heat upon metallic bars, we have, perhaps, approached towards some faint appreciation of the manner in which the solar calorific radiations may, acting on the surface of our planet, produce electrical and magnetic effects.

33. "In 1750, Wargentin noticed that a very remarkable display of *aurora borealis* was the cause of a peculiar disturbance of the magnetic needle, and Dr. Dalton was the first to show that the luminous rays of the aurora are always parallel to the dipping needle, and that the auroral arches cross the magnetic meridian at right angles. Hansteen and Arago have attended with particular care to these influences of the northern lights, and the results of their observations are :—

"That as the crown of the aurora quits the usual place, the dipping needle moves several degrees forward :—

"That the part of the sky where all the beams of the aurora unite, is that to which a magnetic needle directs itself, when suspended by its centre of gravity :—

"That the concentric circles which show themselves previously to the luminous beams rest upon two points of the horizon, equally distant from the magnetic meridian, and that the most elevated points of each arch are exactly in this meridian.

"It does not appear that every aurora disturbs the magnetic needle, as Captains Foster and Back both describe very splendid displays of the phenomenon, which did not appear to produce any tremor or deviation upon their instruments.

34. "Some sudden and violent movements have been from time to time observed to take place in suspended magnets; and since the

establishment of magnetic observatories in almost every part of the globe, a very remarkable coincidence in the time of these agitations has been detected. They are frequently connected with the appearance of aurora borealis; but this is not constantly the case. These disturbances have been called *magnetic storms*, and over the Asiatic and European continent, the islands of the Atlantic, and the western hemisphere, they have been simultaneous.

"From observations made at Petersburg by Kupffer and deductions drawn from the observations obtained by the Magnetic Association, it appears probable that these storms arise from a sudden displacement in the magnetic lines of the earth's surface, but the cause to which this may be due is still to be sought for.

"In the brief and hasty sketch which has been given of the phenomena of terrestrial magnetism, enough has been stated to show the vast importance of this very remarkable power in the great operations of nature. We are gradually reducing the immense mass of recorded observations, and arriving at certain laws, which are found to prevail. Still the origin of the force, whether it is strictly electrical, whether it is the circulation of a magnetic fluid, or whether it is merely a peculiar excitation of some property of matter, are questions which are open for investigation."*

CHAPTER III.

OF THE EARTH AND THE CONDITION OF MATTER AT ITS SURFACE.

35. The matter of which the earth is composed, is collected into a spherical mass, which, in consequence perhaps of the rotation it has about an axis, is slightly compressed at the poles and bulges a little at the equator. The surface of the waters of the ocean is everywhere nearly equidistant from the earth's centre, and is the surface from which all heights or depths are measured. The atmospheric veil extends to an unknown but comparatively small elevation above this, and the extreme depth of the waters of the ocean probably nowhere greatly exceeds the extreme altitude of the mountains which rise above the general level of the plains. All that portion of the solid matter which is permanently uncovered by water, is called *land*. Waters collected in depressions or hollows, entirely surrounded by land, and fed either by running streams or natural

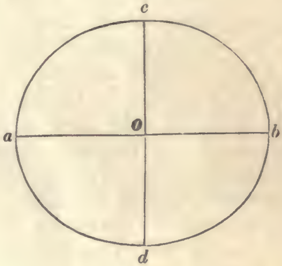
* Hunt's Poetry of Science, *ante cit.* p. 213—217.

springs, are called *lakes,* or *inland seas,* and are usually nearly pure, while those of the ocean and of some lakes, hold in solution a certain proportion of saline matter. It is probable that all water contains a trace of those various mineral substances very generally distributed on the earth, and that it is in a sense a truly universal solvent.

The mean density of the globe is something more than five and a half times that of water (about half that of silver), and as the density of most of the rocks found at the surface is not more than half as great, it follows that the interior is either composed of different proportions of the elementary substances, or that these matters exist there in a far denser state.

36. I append here the best measurements of the earth that I have been able to procure.

Fig. 1.



Our planet is an oblate spheroid, of which the annexed elliptical diagram (fig. 1) is a sectional view; *a b*, represents the longer, or equatorial diameter, and *c d*, the shorter, or polar diameter. *O* is the centre of the ellipse.

The semi-major axis Oa=	20,924,774 ft.
The semi-minor axis Oc=	20,854,821 „
The difference or amount of flattening. . .	69,953 „

It will be noticed that the difference, though nearly two and a half times the height of the loftiest mountain on the surface (28,000 feet), is little more than $\frac{1}{300}$th part of the longer semi-diameter (Oa).

It is not improbable that the extreme difference between the highest mountain peak, and the deepest depression of the sea may be, together, equal to or even greater than the compression.

The surface of the earth, calculated from the above measurements, amounts to about 196,800,000 square miles, which is partly dry land, and partly water, distributed nearly as follows, viz., about in the proportion of 1 to 2·84.

Land	51,500,000	square miles.
Water	145,300,000	„
Total	196,800,000	„

Of the land again it has been estimated, that about 2,150,000 square miles only (about one twenty-fourth part) is distributed in islands, the rest (49,350,000 square miles) being in large masses or continents, Australia, however, being regarded as a continental mass. The water is divided into fresh and salt water, but the proportion of the former to the latter is not more than one to five hundred. (See paragraphs 41 and 44 for further details of this kind.)

It is requisite to observe, that here, and elsewhere, British statute miles have been assumed, as the measure of distance most familiar to the majority of readers. Of these miles there are about sixty-nine and a sixth to a degree of latitude, while of nautical or geographical miles there are only sixty. Thus the statute mile contains

5280 English feet, and the geographical mile 6086. Much confusion has arisen in the measurement of elements of the earth, by want of attention to this considerable difference.

The labour of calculating many of these proportions between land and water and various portions of the land, has been executed by Professor Rigaud. Valuable and independent measurements are also due to Mr. Hughes and others. (See Hughes on the construction of Maps, London, 1843.) It may be well to mention that the method adopted by Rigaud was to ascertain the proportions by weight, after cutting out the land from the best constructed maps that could be obtained. Mr. Hughes' estimate was made by first measuring the actual dimensions of the belts, or zones, extending over each degree of latitude, from the equator to the poles, the whole surface of the globe being taken at 196,861,755 square miles, and the compression at $\frac{1}{304}$, and the results agree very closely with those of Rigaud, but differ considerably from those obtained by Malte Brun, and copied into most works on physical geography. There is little doubt that the more recent determinations are the most accurate.

37. Evidence is not wanting in proof of a higher temperature existing beneath the earth's crust than the mean temperature of the surface at any point. Amongst such evidence must be ranked the observations made in deep wells and mines, at depths often amounting to several hundred yards below the level of the adjacent land; and also the facts observed wherever communication with the interior is afforded, either by the natural issue of water from deep crevices in certain rocks, or by those more striking phenomena exhibited by volcanoes. For all moderate depths the increase of temperature appears to be nearly uniform, commencing at a point where the variations that take place at the surface cease to be felt, and increasing about one degree of Fahrenheit for each fifty-four feet; but there is no evidence to prove that the rate of increase is constant at greater depths than about 1500 feet below the level of the sea ($\frac{1}{7000}$th part of the earth's radius). The rate of increase appears to be affected by the nature of the rock passed through.

The increase of temperature observed in sinking the deep well at Grenelle at Paris, (1813 feet) was at the rate of 1° Fahr. to 58·28 feet. In a very deep mine at New Salzwerk, near Minden, in Prussia, it is 1° in 53·88 feet, to a depth of 2000 feet; and about the same near Geneva, at a considerable depth below the surface, but at an absolute elevation of 1600 feet above the sea. The general result of a very large number of observations in the Saxony mines, at depths of about 2000 feet, gives the increase as 1° in 76·26 feet; but in a deep coal pit in Durham (Monkwearmouth) at a depth nearly the same, it is 1° in rather more than 59 feet. In a very deep Artesian well recently sunk at Mondorf, on the frontier of France and Luxembourg to a depth of nearly 2300 feet, the water at 2200 feet, had a temperature of 93° Fahr., showing an increase at the rate of 1° Fahr. for each 54 feet. See § 111.

38. The atmospheric veil surrounding our earth has a definite limit, probably at a distance considerably less than a hundred miles from the level of the sea, and within these limits it seems to consist pretty uniformly of an admixture of 20·80 parts (by volume) of oxygen, to 79·12 of nitrogen, together with exceedingly small quantities of other substances, of which aqueous vapour, carbonic acid gas,

carburetted hydrogen gas, and ammoniacal vapours, have been clearly determined. The atmosphere performs a most important part in modifications daily taking place on our globe, besides being intimately connected with the existence of organic life. Being highly expansive, the density of the air is found to diminish rapidly as we ascend to greater altitudes.

39. It has been already stated (§ 10, 36) that about three-fourths of the surface of the globe is covered by water, but the land of which the remaining part is made up is by no means level, nor is it distributed so as to form a connected area. Its surface, on the contrary, is in the highest degree irregular; and if the student remember the general arrangement and form of the land, or will examine a terrestrial globe, or a good map of the world, he may at first see nothing in the distribution of the land that appears referable to the uniform action of regular laws. It is, however, the object of science to discover order in the apparent confusion of natural phenomena, and, with the aid of geological research, much that is highly important has been detected even in this department of observation.

It is evident that we must regard the land both in reference to its horizontal and vertical extension, if we would form any notion of its mass above the waves; and should it appear that mechanical force has been exerted to produce the total elevation above the sea, the whole of the raised portion, and not only its mere height, will demand careful attention. We must not then, in treating of the land, neglect to take into account low plains, or plains of moderate elevation, or disregard them while examining the details of mountain chains or plateaux of extremely high ground, and the corresponding

that hour, specially investigated for Toronto, Mohawk, Philadel-
ia, and Sitka.
7. Table of the mean values of the hourly, bi-hourly, or semi-hourly
servations of temperature, for every month, at nineteen stations.
8. Table of the daily fluctuations of temperature derived from the
eceding table, and showing, for every hour and for each month and
year, the difference from the respective daily mean temperature.
Self-registering instruments are absolutely necessary for this kind of
estigation, and when their readings are applied will place the results
a more satisfactory footing, and one commensurate with the import-

Africa, Arabia, India, the Malayan peninsula, &c., are all towards the South Pole. It is also seen in the form of the two Americas, and in the numerous islands and groups of islands in the southern hemisphere. Almost all the principal promontories and peninsulas of the world seem to point southwards.

Another fact in the horizontal extension of land, is the remarkably

5280 English feet, and the geographical mile 6086. Much confusion has arisen in the measurement of elements of the earth, by want of attention to this considerable difference.

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The investigation is one of great interest to the geologist, being intimately connected with the hypotheses concerning the geological chang to which the globe, has been subjected. The fact has been fully esta lished that, in every part of the world where observations have be made, after descending a few feet below the surface or beyond t depth at which the temperature of the ground is affected by variatio in the solar heat, there is a gradual increase of temperature varying the rate of increase at different places, but on an average not far fro one degree in every sixty feet, or a rate which, if continued, would in cate the fusing-point of iron at a depth of about twenty-eight miles.

surrounding our earth has a definite limit, probably at a distance considerably less than a hundred miles from the level of the sea, and within these limits it seems to consist pretty uniformly of an admixture of 20·80 parts (by volume) of oxygen, to 79·12 of nitrogen, together with exceedingly small quantities of other substances, of which aqueous vapour, carbonic acid gas,

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It is evident that we must regard the land both in reference to its horizontal and vertical extension, if we would form any notion of its mass above the waves; and should it appear that mechanical force has been exerted to produce the total elevation above the sea, the whole of the raised portion, and not only its mere height, will demand careful attention. We must not then, in treating of the land, neglect to take into account low plains, or plains of moderate elevation, or disregard them while examining the details of mountain chains or plateaux of extremely high ground, and the corresponding deep gorges. However interesting as picturesque objects, these latter appearances have considerably less effect upon the general mass, and the animal and vegetable inhabitants, than many plains removed only a few hundred feet above the sea.

40. The first point to be discussed is the form of the land, and, as far as it can be determined, the form also of the sea-bottom, considered in reference to horizontal extension. The form of the principal masses of land, or continents, is chiefly triangular, the base of the triangle being towards the north, and the apex towards the south. This is well seen in the Old World, where the principal direction of the land in length is from east to west, while on the other hand, the numerous pointed extremities, such as those of Africa, Arabia, India, the Malayan peninsula, &c., are all towards the South Pole. It is also seen in the form of the two Americas, and in the numerous islands and groups of islands in the southern hemisphere. Almost all the principal promontories and peninsulas of the world seem to point southwards.

Another fact in the horizontal extension of land, is the remarkably

serrated and indented outline of coast of the northern, and especially the north-western part of the Old World, and the comparatively smooth outline of Africa and the two Americas. In the latter continent this is combined with a remarkably perfect system of navigable streams, all emptying themselves on the Atlantic side. In Africa, on the contrary, the oceanic coast line receives hardly any drainage, compared with the extent of the continent.

The whole mass of land is divided into two principal portions, one portion, sometimes called the great continent, including Europe, Asia, and Africa, and the other the two Americas, which are united by the Isthmus of Darien, and also at intervals by the West Indian Islands. The separation of the two great continents is by the channel called the Atlantic Ocean, of which the eastern and western shores seem to correspond to a very remarkable extent, and which, being very much more extended in longitude than in latitude, affects tidal waves, and is affected by currents, rather as a canal than an open ocean.

41. It is not unworthy of notice, that, of the whole area of land (51,500,000 square miles), a very large proportion extends north of the equator, and it also appears singularly arranged in other respects, so that if the globe were divided into two hemispheres the centre or pole of one being in England, that one would contain almost all the land, and the other, with the exception of New Zealand, would be found almost exclusively covered with water. It is also the case, that only about $\frac{1}{27}$th part of the existing land has land directly opposed to it in the opposite hemisphere.

The following table gives, in round numbers, the distribution of the land into its natural and political divisions :—

		Square Miles.	
The great continent	Europe and the adjacent islands	3,750,000	
	Asia and its islands	17,500,000	
	Africa and its islands	11,870,000	33,120,000
America	North America and its islands	7,750,000	
	South America and its islands	6,500,000	
	West Indian Islands	150,000	14,400,000
Australasia	Australia	3,000,000	
	Pacific Islands, &c.	980,000	3,980,000
			51,500,000

42. Without passing beyond the actual limits of direct observation, we find, by the result of soundings, and by other investigations carefully made, that the general configuration of the land is continued to some distance at sea. Thus, if an alteration of level were to take place to such an extent that the sea should in a short time be reduced a thousand feet below its present level, a large tract, reaching from the Scandinavian coast to the islands off the

west coast of Africa, would appear as dry land, deeply indented in a few places, but possibly not altering very much the general form of the European continent. But if this depression of the sea should be continued for another thousand feet, very little further change would be recognised; and thus there are in this case decided physical features, permanent through great varieties of condition, tending to prove that the cause of such phenomena as we have described must be sought for far back in the history of the world, and must have reference to causes of very wide application.

43. The distribution of the water is manifestly dependent on that of the land, and detached oceans are constituted according to the form of the continental masses.

Although properly speaking there is but one great ocean, for it is nowhere so completely cut off and enclosed that a free communication does not exist with other seas, yet the land by its elongation from the Arctic to near the Antarctic Circle, and by numerous bold and marked projections, separates the water into five principal portions, which are called respectively the Pacific, the Atlantic, the Indian, the Arctic, and the Antarctic Oceans. The relative magnitude of these, including the inland seas opening from them, will be seen at once by the following table, and we shall proceed to describe some of their more marked peculiarities :—

		Square Miles.	
The Great Ocean	Pacific Ocean	90,000,000	
	Indian Ocean	23,000,000	
	Antarctic Ocean	2,000,000	115,000,000
The Atlantic Canal	Atlantic Ocean	27,000,000	
	Arctic Ocean	3,000,000	30,000,000
	Total area of Ocean		145,000,000

In addition to the water thus distributed, there is also an area of about 300,000 square miles occupied by the water of lakes and rivers, and of this the great lakes of North America, communicating with the ocean by the St. Lawrence, and the river St. Lawrence itself, form nearly one-half. The mean depth of the ocean has been estimated by Humboldt to amount probably to about 1000 feet.

44. The water of the ocean contains a certain per-centage of several salts in a state of solution, and generally also some gaseous substances. The proportion of salt is larger at great depths, and amongst the gases carbonic acid gas is also more abundant in the deeper parts of the ocean. The mean proportion of solid matter in the ocean has been estimated as somewhat more than thirty-nine parts in one thousand (3·915 per cent) and the different ingredients in one thousand parts (by measure), are thus distributed :—

Common salt	26·910	parts
Chloride of magnesia	5·645	„
Sulphate of soda	4·660	„
Carbonate of lime	1·279	„
Undetermined	·656	„
	39·150	

Taking the mean depth of the ocean, as estimated by Humboldt, to be about 1000 feet, and the area 145,000,000 of square miles, we shall thus have the following totals, reducing the approximate measurement to tons, as the measure of quantity best understood,—

Common salt	6,441,600,000,000,000	tons.
Chloride of magnesia	126,720,000,000,000	„
Sulphate of soda	950,000,000,000,000	„
Carbonate of lime	389,400,000,000,000	„

45. The ATLANTIC, although small compared with the Pacific or great ocean, is much more important to man, whether we consider the actual extent of its coast line, the countries which are enabled by it to hold free communication with each other, or the numerous inland seas connected with it. It extends north and south from the Arctic almost to the Antarctic Circle, with a breadth of less than 1000 miles between Greenland and Norway, of barely 1800 miles at the equator (or rather in 5° south latitude), and not more than 4000 miles at its greatest width between Florida and the coast of Morocco. Its length, if measured from the Arctic to the Antarctic Circle, would be nearly 10,000 miles, but if taken from the Arctic Sea to the latitude of the Cape of Good Hope, which is the part fairly enclosed on each side by land, it amounts to 7000 miles.

Its area is roughly estimated at 27,000,000 of square miles, including the inland seas which open from it, and which are remarkable for their great extent. Amongst them are the Mediterranean and the Baltic in the Old World, and the Gulf of Mexico, the Caribbean Sea, and Hudson's Bay, in the New World.

The opposite coasts of the Atlantic so correspond throughout in their general outline as to give to this ocean something of the aspect of a valley, and the numerous indentations, especially on the eastern side, give a total length of coast line amounting to 55,300 miles,* far more than could be anticipated from the area, and enormously greater in proportion than in the other oceans.

The extent of river drainage emptying into the Atlantic is also exceedingly large, being, in fact, more than double that received by the Pacific and Indian Oceans together, although the area of ocean in the latter case is more than four times as great. Measuring the whole areas from the line of water-shed, it appears that the drainage

* This length is obtained as follows:—

		Brit. st. Miles.
European coast (including North coast of Mediterranean)	19,600	
Asiatic coast (Black Sea, Sea of Marmora, and East coast of Mediterranean)	3,500	
African coast of Mediterranean	2,300	
West coast of Africa	6,900	
		32,300
Atlantic coast of the two Americas and Gulf of Mexico including Greenland		23,000
Total length of coast line		55,300

area of the Atlantic is not less than 26,000,000 of square miles, but of this extent only about 10,250,000 are referable to distinct river systems.

The depth of this ocean is in parts very considerable, soundings having been found in one spot (27° 26′ south latitude, 17° 29′ west longitude), at 14,550 feet, and at another (450 miles west of Cape of Good Hope) at 16,062 feet; while in latitude 15° 3′ south, and longitude 23° 14′ west, a line of 27,600 feet did not reach the bottom. There are few places in which shallow soundings are found at a distance of a hundred miles from the eastern, or European and African shore, but on the western side there are sandbanks of great extent far out at sea, especially off the northern shores of America. The actual termination of the land on the east side is not, properly speaking, the present coast line, but rather a line at no great distance from the shore, beyond which the soundings decrease rapidly, and do not afterwards exhibit shoals. Many important facts concerning the tides and currents of the Atlantic will be noticed in a future paragraph. (See § 125—128.)

46. Of the inland seas opening into the Atlantic the Mediterranean has an area of 950,000 square miles, and affords a navigation of 3500 miles, its extreme length being 2300 miles from Gibraltar to the coast of Syria, and its narrowest part between Sicily and Africa about 90 miles. It receives the drainage of about 1,000,000 square miles of country, and includes a number of islands, of which Sicily, Sardinia and Corsica, the Balearic islands, and the Greek islands, are the most important. The depth of this sea is very great, but the tides are small and variable. Its waters are much salter than those of the Atlantic.

The Black Sea (or Euxine) and the Sea of Azof are to a certain extent subordinate to the Mediterranean, with which they communicate. They together occupy an area of about 250,000 square miles, and drain an area of 1,300,000 square miles. Their waters are only brackish, owing to the large quantity of fresh water which they receive.

The Baltic occupies about 200,000 square miles. Its length measured to the extremity of the main sea (which does not lie in one direction, and includes the Gulf of Bothnia), is about 1000 miles, and its mean breadth is less than 150 miles. The Gulf of Finland runs about 300 miles to the east with a width of from fifty to eighty miles.

The area of land draining into the Baltic includes more than one fifth of the surface of Europe, amounting to nearly 800,000 square miles. Owing to the number and magnitude of the rivers, and the very large quantity of fresh water thus received, and also to the melting of snows from the adjacent high land in the spring and

short northern summer, the proportion of salt contained in its waters is always less than that in the adjacent seas; it varies also considerably. The depth of the Baltic is small, the deepest soundings not exceeding 115 fathoms, while in general a bottom is found at from forty to sixty fathoms. The tides are small, but the water is subject to alterations of level, which have not been yet satisfactorily explained.

The weight of the water taken from the centre of the Baltic, is to that of fresh water as 1·04 to 1, that of the Atlantic is 1·283 to 1. The mean proportion of salt to water in the Baltic, is estimated at only about three per cent., whereas in the water of the open ocean it is, as we have seen, nearly four per cent.

47. The Gulf of Mexico is the Mediterranean of America, but is united by several straits to the Atlantic. It is very nearly divided into two parts by the island of Cuba and the peninsula of Yucatan, which stretch across it from east to west, and the southern and larger part is called the Caribbean Sea. The extreme length of the whole sea is nearly 3500 miles, and it encloses a multitude of islands and reefs, which render the navigation of its entrance difficult. The area of the Gulf of Mexico is estimated at more than 800,000 square miles, and that of the Caribbean Sea at 1,350,000 square miles. The depth is great, and the water extremely warm.

Hudson's Bay is an extensive and nearly enclosed sea on the eastern side of North America, and opens into the Atlantic by Hudson's Strait. Its area nearly equals that of the Mediterranean. It is more than 570 miles across in its widest part, and extends in length for 1200 miles. The depth of water in the middle has been taken at 150 fathoms, but is probably greater. The coasts are for the most part high and rocky, except along the south-western shores.

Baffin's Bay is an extensive gulf, about 900 miles long and 320 in average breadth, and its area is about 400,000 square miles. It reaches far into the Arctic Circle, and its shores are generally high, with perpendicular cliffs, backed by stupendous ranges of mountains, and always covered with snow. Many of the gigantic icebergs that float down the coast of America take their rise in the narrow gorges and clefts of the bold, rocky cliffs at the head of this bay.

48. The Pacific Ocean occupies an area of no less than 90,000,000 of square miles, without including the Indian and Antarctic Oceans, which, however, form part of it, since they communicate by perfectly open passages. It is terminated towards the north by Behring's Straits, which afford a passage, about forty-five miles wide, to the Arctic Sea; and it extends southwards towards the Antarctic Pole, being terminated only as an open ocean by the icebound coasts of Victoria and Enderby's Land, hitherto very imper-

fectly determined. Its average breadth, for a great part of its extent, is not much short of 10,000 miles. Including the Indian Ocean, its coast line is not longer than 47,500 miles,* less, therefore, than the coast line of the Atlantic by nearly 8,000 miles, notwithstanding its much greater extent.

Of this extensive tract of water large portions are enormously deep; and out of the midst of these depths arise innumerable reefs and islands. The shores on the eastern or American side, offer no extensive bays, gulfs, or inland seas, being much less frequently or deeply indented than is the case with the Atlantic. The eastern side is also singularly free from islands, but on the western a range of islands extends parallel to the shore, enclosing the Sea of Okhotsk, the Sea of Japan, the Chinese Sea, and the Yellow Sea, the only representatives of the inland seas which form such remarkable features of the Atlantic.

The general form of this ocean more resembles that of a wide, open, natural basin than is the case with the Atlantic, but an extensive portion extending within the tropics far eastward from the Malayan peninsula, being greatly interrupted by numerous islands and coral banks, the tidal wave is impeded as it advances, instead of being increased, as it is by the long, narrow, meridional channel of the Atlantic.

The currents in the Pacific are less considerable in magnitude and force, and in so far are less important, than in the Atlantic. Its shores exhibit the remarkable phenomenon of a complete fringe of volcanoes, and the central and western part of its bed is supposed to present an area of recent and present depression. Its whole eastern, northern, and southern portions are singularly free from islands of any kind, while in the western part are the most remarkable groups and the most interesting and extensive islands that exist on the globe. Of those in the open ocean almost all are either volcanic or coralline, the former generally rising to a peak, and the latter containing one or more shallow lakes or lagoons. Extensive and remarkable peninsulas project from the bordering continents, chiefly on the Asiatic side, where, as we have said, there exists a complete fringe of islands, extending so continuously that no part of the eastern shores of the great continent is reached directly by the waters of the Pacific.

49. The shores washed by the Pacific may, on the whole, be described as high and rocky, offering in this respect a contrast with the Atlantic, whose coasts are to a great extent sloping, and not scarped. This is explained by the fact that most of the principal mountain ranges occur parallel to the Pacific coast of America, and

* The eastern and southern coasts of Asia measure about 27,000 miles, and the east coast of Africa about 5500 miles. The American coast of the Pacific may extend to 15,000 miles.

at no great distance from it, while the principal mountains of the Old World are across the continent, in its centre, and not in the direction of, or very near, either coast.

The inland seas connected with the Pacific offer no peculiarities requiring special notice. All those on the east coast of Asia partake of the nature of open gulfs and bays, and have several communications with the ocean.

50. The Indian Ocean is sometimes regarded as an appendage to the Pacific, and is estimated to occupy 23,000,000 of square miles. It includes the Red Sea, the Persian Gulf, the Arabian Sea, and the Bay of Bengal, of which the two latter are open gulfs, and the former a sea of small dimensions.

51. Land does not extend so far as either to the North or South Poles of the earth, and the cold icy seas within the Arctic and Antarctic Circles are called respectively the Arctic and Antarctic Oceans. The former contains about 4,000,000 of square miles, and is connected with the Pacific by Behring's Straits and with the Atlantic by the wide strait between Norway and Greenland, its extreme breadth being about 2,000 miles. The Antarctic Circle probably contains more land than the Arctic, and the extent of the Antarctic Ocean must be reckoned as smaller; but little is known of these parts of the world, the climate being far more excessive, and the land much less approachable, in very high latitudes in the southern than even in the northern hemisphere.

The Arctic Ocean has a coast line of not less than 6,000 miles, of which about one half is Asiatic. It drains a vast tract of country in Asia, and a considerable portion of North America; and its Asiatic coast is broken into some very extensive gulfs and inland seas, of which the White Sea is the most known. The whole area of its drainage is probably not less than 8,000,000 of square miles. The Antarctic Ocean probably receives no water from the snow-covered land which has been discovered to exist near the South Pole, and which alone approaches it, but large quantities of ice are separated every year from the cliffs, and drift down into warmer seas.

52. Almost all the different rivers of the globe either directly or indirectly empty themselves into the sea, or else enter some continental lake, where the evaporation or absorption equals the supply of water afforded; and thus the whole of the land receiving rain, and not immediately absorbing or evaporating it, may be marked out into areas of natural surface drainage, called river basins or river systems. Of these a very large proportion of the principal ones pour their tribute into the Atlantic Ocean, and only a few of any importance into the Pacific. Most of the great rivers of Northern Asia, and some of the North American streams, however, empty themselves

into the Arctic Ocean, and some terminate in the Aralo-Caspian depression, or in the plateau of Central Asia. The largest river on the globe, measured by the volume of water brought to the sea, appears to be the Amazons, which drains an immense country, and carries a current of fresh water into the ocean to a distance of three hundred miles from the coast line. The Mississippi, La Plata, and the Orinoco, other gigantic rivers of America, are also remarkable for their vast extent, and the interest attaching to them in respect of the land they drain. The great rivers of India, the Ganges, the Euphrates, and others; the rivers of China, and those that empty themselves into the North Polar Sea, come next in order of magnitude and extent; and, lastly, the rivers of Europe, which, however, are well worthy of notice for their influence on cultivation, and their absolute importance owing to geographical position.

53. The following extract from Johnston's edition of Berghaus's "Physical Atlas" (Description of Hydrological Map No. 5), will enable the reader to understand fully the meaning of the annexed table of the principal rivers, river systems, and systems of drainage. The third column gives what is called the development of the river:—

"To ascertain with accuracy the comparative extent of a river basin, it would be necessary to have an exact knowledge of its superficial contents, and of the geographical positions and forms of its limits. But, however desirable, this cannot be attained in the present state of our knowledge. There are few trigonometrical maps, even of the countries watered by the principal rivers of Europe, on which to base such measurement; while the sources of many of the great rivers of Asia and America are altogether unknown. Hence all such comparisons as are here attempted must be received as the most general approximations. But, in order that these may have any real value, it is necessary that the maps used as the basis of calculations should be the best that can be procured, and that a proper system of measurement should be adopted. Ludwig Müller was among the first who paid special attention to this branch of hydrography, and his method has, with certain modifications, been followed in the construction of the accompanying tables. 'In order,' he says, 'to ascertain the area of a river basin, take a general map, on which the whole extent of the river with its affluents is delineated; and having, with a needle, made a puncture at the source of each stream, turn the back of the map and unite all the punctured points by straight lines; then divide the figure thus formed into as many triangles as it has sides (less two), and reckon each triangle by the scale of miles on the map, when the sum of all the triangles will give the extent of the river district in square miles.' From this statement it is evident that Müller made no allowance for the globular form of the earth, or for the difference between its polar and equatorial diameter; this, added to the less accurate knowledge of many countries when he wrote (1807), renders his results of little present value; and this remark applies to many such tables of a later date, in calculating which, the effect of the kind of projection of the map used, and the spheroidal form of the globe, have been entirely overlooked. In the accompanying tables, the calculations have been made on the plan explained by Müller, modified by the adoption of more correct data, and altered in accordance with our present more extended geographical knowledge. To the extent of area in the table, two columns have been added, one showing the direct distance of the principal streams from the source to the mouth of each, and the other the length of each, including all its windings and sinuosities."

Region	Basin	Names of Rivers.	Area of drainage in British statute square miles.	Length of course in Brit. stat. miles. Direct.	Including windings.
		Atlantic System.			
Europe (area 1,618,000 square miles).		Rhine	87,000	410	700
		Elbe	56,000	400	780
		Loire	45,250	375	600
		Douro	40,000	300	500
		Garonne	32,500	225	370
		Seine	30,000	250	400
		Tagus	29,000	410	550
		Guadiana	26,000	275	480
		Guadalquiver	20,000	205	300
		Weser	17,500	230	320
		Minho	15,750	125	220
		Thames	6,500	130	220
	Baltic (312,500).	Neva	89,500	360	500
		Vistula	75,500	320	600
		Oder	52,000	320	550
		Dwina	44,500	320	650
		Niemen	43,250	275	530
		Pregel	7,750	70	115
	Euxine (791,000).	Danube	310,500	1000	1750
		Dnieper	226,000	630	1250
		Don	224,500	460	1150
		Dniester	30,000	410	520
	Mediterranean (810,000).	Po	40,000	260	400
		Rhone	37,000	285	640
		Ebro	33,000	310	480
Africa (2,300,000).		Nile	700,000?	1500?	2500?
		Niger	600,000?	1400?	2600?
		Senegal	1,000,000?	?	?
		Orange River		?	?
		Gambia		?	?
		Coanza		?	?
		Rio Grande		?	?
America (8,755,000).	North (425,000).	St. Lawrence and the great lakes	402,000	975	2050
		Connecticut	11,000	265	300
		Delaware	12,000	205	300
	Gulf of Mexico (1,655,000).	Mississippi-Missouri	1,300,000	1600	4000
		Rio del Norte	250,000	1400	2000
		Magdalena	95,000	640	1000
		Motagua	10,000	215	300
	South (4,375,000).	Amazons	2,000,000	1780	?
		Plata	1,175,000	1180	2200
		Tocantins	380,000	1150	1300
		Orinoco	335,000	425	1550
		St. Francisco	250,000	1000	1600
		Paranahyba	153,000	640	860
		Essequibo	82,000	400	480
			10,374,000		

Names of Rivers.		Area of drainage in British statute square miles.	Length of course in Brit. stat. miles. Direct.	Including windings.
Pacific System.				
Eastern Asia (2,353,500).	Amour	777,000	1400	2750
	Yang-tse-kiang	727,000	1750	3300
	Hoang-ho	716,500	1325	2650
	Tche-kiang	133,000	575	1200
Indian Ocean (2,463,500).	Ganges and Brahmapootra	576,500	950	2000
	Irawadi	440,000	1250	2500
	Indus	415,000	1030	2300
	Menam	288,000	700	1100
	Euphrates	260,000	680	1720
	Godavery	124,000	620	850
	Kistna	110,000	500	800
	Zambeze (Africa)	250,000?	800?	?
America (485,000).	Columbia	260,000	670	1540
	Colorado	225,000	580	920
		5,302,000		
Arctic System.				
Asia (3,782,000).	Obi	1,233,000	1475	2650
	Yenesei	1,050,000	1400	3200
	Lena	800,000	1400	2750
	Kolyma	150,000	515	950
	Dwina	140,000	460	1000
	Indigirka	115,000	640	1050
	Olenek	104,000	685	1150
	Anadir	85,000	?	?
	Petchora	65,000	410	685
	Mesen	40,000	?	?
America (1,250,000).	Mackenzie	600,000	1100	2400
	Saskatchevan	480,000	765	1030
	Churchill	100,000	1050	1900
	Albany	70,000	440	640
		5,032,000		
Continental System of Asia.				
Caspian (727,000).	Volga	530,000	1030	2750
	Oural	110,000	630	?
	Kour	87,000	345	740
Aral (580,000).	Sir	320,000	680	1350
	Amoo	260,000	920	1600
Lob lake, rivers, &c.		240,000	685	1260
		1,547,000		

54. The real drainage received by the different oceans is, however, much greater than appears by the preceding table, since there are many large areas and innumerable smaller ones not strictly included in any system, and drained by streams of smaller size and less importance. These together almost equal the areas referred to in the table, and are thus distributed :—

			Area in square miles, drained by large river systems.	Area in same tract not accounted for.
Drained by the chief river systems in Europe and Asia.				
1. into the Atlantic Ocean.				
a. from the European coast	405,500			
b. into the Baltic	312,500	1,619,000		
c. „ Mediterranean	110,000			
d. „ Euxine	791,000			
2. into the Pacific Ocean		2,353,500	11,515,000	9,735,000
3. „ Indian Ocean		2,213,500		
4. „ Arctic Ocean		3,782,000		
5. „ Central Asiatic basin		1,547,000		
Drained by the chief river systems in Africa.				
1. into Atlantic Ocean.				
a. from west coast	1,600,000	2,300,000		
b. into Mediterranean	700,000			
2. into Indian Ocean		250,000	2,550,000	9,320,000
Drained by chief systems in North America.				
1. into Atlantic Ocean.				
a. from east coast	425,000	1,975,000		
b. into Gulf of Mexico	1,550,000			
2. into Arctic Ocean		1,250,000	3,710,000	4,040,000
3. into Pacific Ocean		485,000		
Drained by chief systems in South America.				
1. into Atlantic Ocean.				
a. from east coast	4,375,000		4,480,000	2,020,000
b. into Caribbean Sea	105,000			
Total drained by river systems			22,255,000	
Estimated area of Australia (river systems not known)				3,000,000
Area of West Indian, Pacific, and other islands not included				1,130,000
				29,245,000
Add area drained by river systems				22,255,000
Total area of land on the earth				51,500,000

55. From this large area a certain portion must be deducted as receiving no rain, and therefore admitting of no drainage. Thus, in the northern part of Africa and in Arabia, nearly 6,000,000 of square miles of country receive either no rain, or so little as to involve no surface drainage ; and in Central Asia another area of more than 2,500,000 square miles is in a similar condition. In America there are also rainless regions, one on the coast of Peru and Bolivia, another in Mexico, and a third on the northern coast of South America at Venezuela, amounting in all to nearly 1,000,000 square miles.

But, if we deduct these areas (making in all 9,500,000 square miles), we still have as much as 20,000,000 square miles drained by small streams, and not forming part of the principal river basins.

56. The lakes or inland seas, chiefly of fresh water, either not communicating at all with the ocean, or only communicating by rivers, come next under consideration. By far the most extensive of them occur in North America; but there are also considerable areas of land thus covered in the old world, and others whose level is far below that of the adjoining sea, and which would be covered by water if the evaporation were not greater than the supply from rain. The existence of lakes has little reference to absolute elevation, and they are due either to the form of a river-bed, expanding at some point and containing the water thus introduced, the velocity of the stream being diminished or destroyed; or else to the filling with water of some natural hollow, sometimes by springs, but more generally by streams, the supply from which is greater than the evaporation.

The principal North American lakes are five, and they together cover an area of more than 120,000 square miles. Their dimensions and elevation above the sea will be found expressed in the following table:—

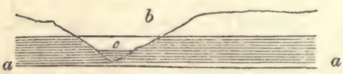
	Total length in Brit. sta. miles.	Mean breadth in Brit. sta. miles.	Mean depth in feet.	Elevation above the sea in feet.	Area in square miles.
Lake Superior	460	90	900	596	42,000
Lake Michigan and Green Bay	480	80	1000	578	32,000
Lake Huron	275	92	1000	578	27,500
Lake Erie and Lake St. Clair................	300	46	84	565	11,500
Lake Ontario............	205	40	500	232	7,200
					120,200

Besides these, a vast multitude of others exist in the northern parts of the same continent, some of considerable magnitude, and many of them the centres of basins of drainage of a wide extent of country. On the western side of the Rocky Mountains, in Mexico, and in various parts of South America, are also remarkable lakes, some being very large, others only covered with water occasionally during periodical inundations; and others again, as the Lake Titicaca in the Bolivian Andes, presenting a broad sheet of water at an elevation of many thousand feet above the sea.

57. The lakes of Europe and Asia are smaller in extent than those of America, but not less interesting in their associations. The Caspian Sea and the Sea of Aral occupy the lowest part of a vast space, whose whole extent is not less than 100,000 square miles,

hollowed out, as it were, in the central region of the great continent, and, no doubt, formerly the bed of an ocean. The Caspian Sea has the lowest level, its surface being 83½ feet below the level of the sea, its area 24,000 square miles, and its depth in some parts 600 feet. The Aral Lake is of smaller size, having an area of only 4500 square miles, and it is also much less deep.

Fig. 2.
Depression of the Dead Sea.



a. Level of the Mediterranean.
b. Position of Jerusalem.
c. Level of the Dead Sea.

The lakes in Asia Minor are even more remarkable than these in their considerable depression below the sea-level, the Lake of Tiberias being 466 feet below the Mediterranean, or even more according to some travellers, and the Dead Sea 1388 feet. The depth of water in the Dead Sea exceeds in some places 300 fathoms. Some idea of the depression will be obtained by looking at the annexed diagram, fig. 2.

There are large and somewhat important lakes in Central Asia, of which the Lake Baikal alone has an area of nearly 24,000 square miles. Other numerous sheets of water, generally of much smaller size, are scarcely known to European geographers. The lakes of Europe also are interesting, the largest of them, Lake Ladoga, having about 1400 square miles of surface. The Swiss and Italian lakes are of much more limited area, but are, some of them, at a considerable altitude above the sea, and of considerable depth. Lastly, we may refer to Africa and Australia as countries in which extensive tracts are covered with water, although too little is known of their actual extent to enable us to compare them with the lakes of America or Asia.

In Northern Africa the Lake Melghigh is 160 feet below the level of the Mediterranean, and another lake near the Red Sea, in the country of Adel, has been described as more than 600 feet below the level of the Arabian Gulf. It is not unlikely that the great salt tracts in many places are the result of the evaporation of sea-water left in hollows, and enclosed by some natural barrier.

58. Most of these depressed lakes contain water loaded not only with common salt but with other soluble salts, especially of magnesia, the quantity of which is sometimes exceedingly great. In the Dead Sea saline ingredients are present to the extent of 26¼ per cent., by far the larger proportion being chloride of magnesium.

A small lake on the steppes, east of the Volga, having an area of about 150 square miles, contains no less than 29·13 per cent. of solid matter, and supplies a large proportion of the salt used in Russia. The salts are chlorides of potassium, sodium, and magnesium, and sulphate of magnesia, according to the following analysis by H. Rose:—

Chloride of potassium	0·23
„ sodium	3·83
„ magnesium	19·75
Sulphate of magnesia	5·32
	29·13

59. The surface of land uncovered by water may be divided thus. 1st, *low plains*, or tracts of moderately unbroken country, whose mean level is not many hundred feet above the sea even towards the interior of continents, and is much less than that near the embouchure of the rivers that traverse them; 2nd, *high plains* or *table lands*, generally more than a thousand feet above the sea in the interior, and rising at once many hundred feet even near the sea; and 3rd, *mountain tracts*, where the elevations above the general level put on a distinct and abrupt character, whatever their actual or relative elevation may be. The elevations that break the surface of plains are called *hills*, also without much reference to absolute elevation.

Regarded in this sense, not only every continent, but even every part of a continent, and most islands of moderate size, can generally furnish plains and plateaux, hills and mountains, although on careful comparison, and when we understand the real physical value of such modifications of the form of land, there will rise out of this apparent confusion important and distinct systems connected with changes that have taken place by the action of mechanical force beneath the earth's surface.

60. The lower levels of the earth are sometimes merely spoken of as plains, and sometimes as river-valleys; but when presenting features more distinctly marked, they are *steppes* or *deserts*, *prairies*, *savannahs*, *llanos* or *silvas*. Amongst them are the richest and most fertile districts upon the earth, and also the most hopelessly barren and useless tracts that the imagination can picture. They include the treeless expanses of one part, and the impenetrable forest-districts of another part of South America; the plains of Northern and Eastern Europe yellow with ripe corn, and the Sahara of Africa yellow also, but with the dry sand that fills the air and destroys every form of vegetable or animal existence.

It would be impossible in a work of any moderate extent, even if devoted entirely to the subject of Physical Geography, to enumerate and describe all the moderately elevated plains of the earth; and here, where only a very general outline is attempted, such detail would be quite out of place. We may, however, with advantage speak of some of the more remarkable of the appearances they exhibit, for "in every zone nature presents the phenomena of these great plains, and in each they have a peculiar physiognomy determined by diversity of soil, by climate, and by elevation above the level of the sea."* We may also add that, however little attended

* See Humboldt's "Aspects of Nature" (Ansichten der Natur, the third German edition of which, with notes, has been admirably translated into English by Mrs. Sabine, and is recently published), a work perhaps the most original and suggestive of any of the valuable contributions to science made by its venerable and distinguished author. Frequent use will be made of it in this chapter.

to, these portions of the earth are the most instructive, when properly known, in illustrating many points by which Geology derives assistance from Physical Geography.

The plains of Northern Europe are extensive and well characterized, occupying more than two-thirds of the surface of the continent, and extending eastwards from the German Ocean along the south shores of the Baltic as far as the Ural Mountains, including Holland, North Germany, and the whole of European Russia. The Asiatic low lands are even more extensive; the plain of Siberia reaching across to the Pacific, and from the highlands of Asia to the Arctic Ocean; those of China, Hindostan, and Independent Tahtary, likewise occupying large tracts. Africa also presents in its turn tracts of low land, one of which, at least, is of vast extent, and characterized by the most complete sterility, the Great Desert or Sahara, occupying an area of nearly three millions of square miles, and enjoying a smaller share of the gifts of nature than any other portion of the globe of equal magnitude, although by no means uniformly barren.

61. The districts thus affording few or no real elevations of considerable amount are not all perfectly level, since a large portion consists of rolling or hilly land, generally more picturesque and interesting, and often more valuable than the rest. The land presenting this intermediate condition, however, is not very easily determined, and there are no calculations at present to be depended on by which we can tell the limits either of the actual or relative capabilities of the heaths of Europe, the steppes of Asia, or the deserts of Africa. It may be sufficient to state that with the exception of the table land of France, and Central Germany, and the mountain districts of the Alps, Pyrenees, and Carpathians and Scandinavia, the whole of Northern Europe, whether fertile or barren, and whether flat or hilly, exhibits marks of recent marine action, so that we may often perceive in places now not reached even by the rivers, that there has formerly been a deposit of water-conveyed materials, and also a wearing or denuding action of powerful marine currents.

62. The low plains of Europe include many river-valleys, enclosed by high and mountainous ranges, but the larger portion is not of this nature, consisting chiefly of open and heath-covered tracts on the shores of the Baltic, embracing, as we have already said, much of Prussia and Russia, and also of Denmark, and having a mean elevation of about 360 feet above the level of the sea.

Far in the east of Europe, and on the borders of Asia, is the great Aralo-Caspian tract, a part of which, the Kirghis steppe, occupies nearly 15,000 square miles of almost unbroken surface, depressed nearly 100 feet below the general level of high water in the ocean. It is terminated by much loftier table lands occupying a principal space in Central Asia, but these decline towards the Arctic Ocean,

descending to the plains of Siberia, whose elevation is probably nearly the same as, though somewhat greater than, that of the European plain. On the south-eastern side of the same lofty range the alluvial tracts of China occupy 300,000 square miles, while on the southern side of the Himalayan chain the plains of India extend, watered by the Ganges and Brahmapootra. Between China and India we have the low valley of the Irawaddi, as large as the whole of France; and on the west of India, the Punjaub, and the great Indian desert with the valley of the Indus, reach almost to Beloochistan, low lands also extending towards the Persian Desert and Arabia, which are separated from the low table land or Desert of Africa by other, but higher plateaux.

63. The Sahara, the widest extent of low plains in the great continent, reaches from the rocky country beyond the valley of the Nile to the shores of the Atlantic, a distance of not less than 2650 miles, and its width varies from 700 to 1200 miles. Its surface is generally naked, hard sandstone rock, or loose sand, with intervening portions covered by gravel or rounded pebbles; here and there a little earthy matter or salt is mingled with the sand; and fertile spots—the *oases* of the desert—watered by springs, are met with at distant intervals. The largest of them is about 100 miles in length, and from one to fifteen miles broad. Throughout the greater part of its extent this desert is probably very little raised above the level of the Atlantic, and some parts seem actually below that level. No rain falls in the district, and there is, therefore, no natural drainage.

64. The New World presents very large tracts of low land only recently emerged from the ocean floor, each of the vast rivers which characterize that continent running through a plain known by some distinctive name. Thus, the Amazons waters a tract measuring not less than 1500 miles in length, and varying in breadth from 300 to 800 miles (comprehending an area of 1,200,000 square miles), almost covered with gigantic and unbroken forest, and hence called *silvas.* Over this tract the quantity of rain that falls during the wet season is larger than the annual fall in any other part of the world.

The *pampas* are treeless plains, occupying about 2000 miles of country, and extending from the forest desert of the Amazons to the southernmost limits of South America, with a breadth of from 200 to nearly 500 miles, presenting in this range a great variety of surface, climate, and vegetation. The country gradually rises from the Atlantic shore to the foot of the Andes, and, roughly estimated, may be considered as including nearly 1,000,000 square miles.

The *llanos* are also treeless plains, and extend along the banks of the Orinoco, for the most part within the tropics, but their extent is not more than half that of the pampas: during one half of the year they are covered with grass, and for the rest desolate.

65. The basin of the Mississippi, the greater part of which has a mean elevation of about 500 feet above the level of the sea, contains gigantic *prairies* and *savannahs*, which form such characteristic features of North American scenery. These occupy a space of nearly 1,000,000 square miles; so that, on the whole, more than one-fourth part of the area of the two Americas is only just removed above the level of the sea, and is drained by four principal rivers, the Amazons, the Plata, the Orinoco, and the Mississippi, and their tributaries. The plains of smaller extent, of which the number is of course exceedingly great, do not appear in this calculation.

In addition to the large low tracts already mentioned, there can be little doubt that others, of great extent and low elevation, remain to be discovered in South Africa and in Australia.

66. Elevated plains are phenomena by no means so frequent on the earth, or so extensive as those low plains we have been considering. The most remarkable, for their extent and influence on the physical features of the globe, are those of Central Asia, Mexico, Quito, part of South Africa, Abyssinia, Hindustan, Spain, Bavaria, and France. The following table will give an idea of the relative importance of some of these :—

	Estimated area in square miles.	Mean elevation in feet.
Plateau of Auvergne (Central France)	18,000	1,087
" Bavaria	8,000	1,663
" Castille (Central Spain)	100,000	2,239
" Iran (Persia)	60,000	2,500
" Mysore (Central India)	56,000	2,942
" Caraccas (South America)	5,000	3,070
" Gobi (Central Asia)	600,000	4,220
" Popayan	2,000	5,756
" California (the great basin)	150,000	6,000
" Abyssinia (round lake Tzana)	?	6,076
" South Africa (Orange River)	?	6,395
" Abyssinia (Axum)	?	7,034
" Mexico	50,000	7,483
" Quito	5,000	9,528
" Province de los Pastos	4,000	10,231
" Thibet	50,000	11,510
" Lake Titiaca	30,000	12,853

Arabia also exhibits table-lands of some extent and considerable elevation, and there are many others not mentioned in the table.

67. Very incorrect ideas have been entertained of the extent and elevation of lofty plateaux in most parts of the world, and the areas approximately given in the preceding table, of which the plan and most of the details are copied from Humboldt,* can only be regarded as useful guides marking some limit. The usual character of these districts is greatly dependent on the mountain-chains with which they are always associated, either directly or indirectly; and the fact of

* "Aspects of Nature," Eng. tr. vol. i. p. 78.

the existence of such plains often merely intimates in reality that there has been a broad and deeply seated axis of elevation; that the mountain-chain parallel to the principal direction of the plains exists as a group of ridges rather than one single main elevation; and that we are in the vicinity of places where the fundamental forms of land and the direction of its distribution may fairly be looked for. Viewed in this light, they are instructive and suggestive, and in all the higher problems of Physical Geography must be regarded with great interest.

68. The determination of the mean height of continents or portions of them is equivalent to finding the centre of gravity of the masses of land they present above the sea, and an enumeration of the volume of each and its effect on the whole forms a good comparative estimate of the true importance of mountain-ranges and plains.

The position of the centre of gravity or the mean height of all the solid parts of the earth's surface above the sea has been estimated by Humboldt at about 1000 feet, that of all Europe 671 feet, Asia 1132 feet, South America 1151 feet, North America 748 feet, and the two Americas together 940 feet.

The effect of the plateau of Spain on all Europe is estimated at 36 feet, and that of the whole chain of the Alps only 20 feet. In Asia the great central plains are estimated to contribute 120 feet of elevation to the mean. It should be understood that these results can only be regarded as approximate, and that the calculations give a maximum limit. ("Cosmos," vol. i. p. 293.)

69. The mountain-chains of the earth can only be conveniently regarded in this slight sketch of physical phenomena so far as their uniformity of direction, their physical character and conformation, and their mass, give them importance by connecting together the rest of the land on the globe.

If the student will examine a terrestrial globe, or even a good map of the world, he will recognise two main directions along which the principal mountain-chains are grouped, and also a number of transverse spurs proceeding from them. In the Old World (Europe, Asia, and Africa), the space between two such lines forms a belt, commencing in Europe with the Pyrenees and the plateau of Spain, and in Africa with the Atlas Mountains, and continuing towards the east till they meet in Western Asia, after which they are both continued together further east, terminating finally on the shores of the Sea of Okhotsk and the coast of China. In the New World, a similar belt reaches from the north-western extremity of North America, and extends to the very southernmost point of South America. Within the wide embrace of the enclosing ridges of each of these mountain-chains are contained most of the lofty plains already alluded to; and between their flanks and the sea, but sometimes also enclosed within them, are the lower plains and river valleys. They mark out the great features of the globe; and in their own detail, and in the chains which spring from them and are connected with them, we may read the history of the world; since all we know of its present structure, and all our means of knowing its past history, is dependent on the

successive and slow but irresistible upheavals that have lifted these masses from the general level of the water.

70. The ridges of the mountain-chains of the Old World are the Alps and Pyrenees in Europe, the Atlas Mountains, and perhaps the Mountains of the Moon in Africa, and in Asia, the Caucasus, a connecting link between Europe and Asia, the Hindoo Koosh, the great Himalayan chain, and the chain of the Altai Mountains, with their eastern extensions into China and Mancheu Tahtary. Many others might be mentioned, but these are the most important, and involve most of the points of chief interest. They include the most massive as well as the loftiest mountain masses, the breadth of the chain between Siberia and India being as much as 1500 miles, and the extreme length about 10,000 English miles. The greatest heights attained are in the Himalayan chain in about 80° east longitude, and exceed 28,000 English feet above the mean level of the sea. The position of the crest of most highly elevated land is between 81° and 118° east longitude; and thus it is that, while the mean height of Europe is estimated at not more than 670 feet, that of Asia is more than half as much again, notwithstanding the wide expanse of low lands in Siberia, and large tracts in Western Asia actually below the level of the ocean.

71. The mountains of America form a more simple and complete chain than those of the Old World, but still present considerable differences of breadth and height. The Andes of the south and the Rocky Mountains of the north are connected by the lofty plains and ridges of Mexico, and thus form an uninterrupted range, extending for more than 60° of latitude on each side of the equator, giving for the total length of the line of elevation a distance of not less than 9000 miles. The breadth, however, is rarely considerable; and although in North America the range divides, and its two principal arms include a distance of 300 or 400 miles, the intermediate plains are by no means so lofty as to affect the general mean elevation of the continent, as is the case with the high lands of Central Asia, and even those of Mexico.

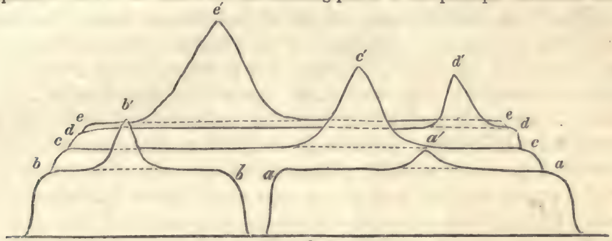
72. All the mountains hitherto referred to form part of the main chains; but there are also others setting off from them, or, in some cases apparently unconnected, and having a different principal axis. Thus the Ural Mountains form a meridional chain quite distinct from the main group across Europe and Asia; and the coast-chain of Venezuela and the mountain systems of Columbia and Guyana in South America partake in some measure of the same character. North and south chains in the Old World are also found in South Africa and Madagascar, in India, in the peninsula of the Birman empire, and in China; while the principal chain in Australia, at least on its eastern side, follows the same direction. The mountains of

Brazil range nearly parallel to the east coast of South America, and the Alleghanies to the corresponding coast of North America.

73. A diagram is subjoined (fig. 3), which shows the mean elevation of the principal mountain-ridges, and that of their culminating

Fig. 3.

Comparative View of the Crests and Culminating points of the principal Mountain-chains.



		feet.		feet.
a a	Crest of the Pyrenees	8000	*a′* Pic Nethou	11,168
b b	" Alps	7700	*b′* Mont Blanc	15,743
c c	" Andes of Quito	11,800	*c′* Chimborazo	21,420
d d	" Bolivian Andes	15,200	*d′* Illimani	21,149
e e	" Himalaya	15,700	*e′* Dhawalagiri	28,072

points. It will be manifest to the eye, that the Himalayan chain (*e e*) is the loftiest in every respect, although the actual crest does not range more than 500 feet above that of the Bolivian Andes (*d d*). The latter mountains, however, extend only for a distance of 500 miles, while the Himalaya group ranges through no less than fifteen degrees of longitude, which, in latitude 30°, is equivalent to upwards of 900 miles. Within the range of the Bolivian Andes occurs the singular plateau of Lake Titiaca, at an elevation of nearly 13,000 feet above the sea; and the next highest plain is that of Thibet, amongst the Himalayan Mountains, its elevation being between 11,000 and 12,000 feet.

74. The mountains of the earth are not all of them included in these systematic and distinct groups, for we meet with many striking deviations from the usual direction, and we also meet with isolated peaks, rising suddenly and boldly from low plains or small islands. The former are in all cases phenomena worthy of close study, for the deviation from the prevailing direction will generally prove to be the result of elevating forces, acting at some period either long antecedent or subsequent to that of the main axis of elevation, and thus serves to connect the present condition with past history. Such isolated mountains are usually conical in form, and present marks of having recently served as open vents, by which burning and intensely heated substances, elaborated in the bowels of the earth, are sent out into the air, and there enter into new combinations. Such cases are almost confined to a moderate distance from

a coast line, except, indeed, in the remarkable and recent volcanic mountains of the Celestial Mountains (Thian-Schan), whose nearest ocean is 1800 miles distant, and which is 1200 miles from any considerable body of water. The grouping, position, and phenomena of volcanoes will, however, demand further consideration in another place.

75. However sudden the transition may seem, we really pass very naturally from the consideration of mountain-chains to that of islands, which appear in groups of two kinds, the one fringing a coast line, and manifestly having some relations of form to the adjacent continent; the other kind including detached islands, far removed from land, and either forming independent chains or being isolated mountain-tops. Islands, in fact, are nothing more than belts or detached portions of lofty plateaux, whose subordinate low plains form the ocean bottom, and whose tops reach above the level of high water. Similar prominences above the general level, which do not quite reach that level, are called banks and shoals, of which examples on a large scale are seen in the great Bank of Newfoundland, the Agulhas Bank off the south coast of Africa, and the Chagos Bank, amongst the coral of the Coralline Sea in the South Pacific.

76. Viewed in this light we may at once place as belonging to the first or continental group, the vast series, commencing with what has been called the Australian chain, or rather with New Zealand, and continued by Norfolk Island, New Caledonia, and the New Hebrides, the Salomon and Louisiada Archipelagos, and New Guinea, as far as the Moluccas. This belt of islands is throughout parallel to the coast line of Australia, and is continued by Timor, Java, and Sumatra, the Nicobar and Andaman islands, parallel to the Malayan peninsula and the island of Borneo. Another range may be traced going northwards by the Philippine Islands, Formosa, the Loo Choo Islands, and the Japanese Islands, to the Kurile Islands and Kamtchatka, enclosing the Chinese and Japan Seas, and in close parallelism to the east coast of Asia. The Aleutian Archipelago is in a similar way parallel to the line of coast stretching out between America and Asia; and a small range of islands may be observed parallel to the coast of Russian America, reaching down as far as Vancouver's Island.

Other principal continental islands are seen in the Gulf of Mexico, where a line drawn through Portorico, San Domingo, Jamaica, and Cuba to the peninsula of Yucatan, will be found parallel with the north coast of South America and the east coast of Guatemala.

So, also, in Europe the coast of Scandinavia, the British Isles, the islands of the Baltic, the islands between Spain and Italy, and those in the Adriatic, as well as those in the Greek Archipelago, present similar and sufficient examples; and near Africa the Island of Madagascar and the Sechelle group are of the same kind.

77. The islands not referable to existing continental land may possibly in many cases be portions and indications of ancient land now depressed below the sea-level. The wide tract in the Pacific and elsewhere, occupied by coral, and presenting steep cliffs of that substance, barely removed above the level of low water, is probably of this kind ; and thus the Low Archipelago and the Society Islands, with a multitude of other smaller groups between these and the Caroline Archipelago may be, though apparent exceptions, only concealed examples of the general principle. There are, however, some other exceptions, referable chiefly to volcanic districts, and due probably to local elevation in connection with earthquake and volcanic disturbances. St. Helena and Ascension Island, the Cape de Verde Archipelago, the Galapagos Archipelago, and some others are known to be of this kind.

78. It should not be lost sight of, in taking this view of the physical features of the earth on a large scale, that the coast-lines to which the chains of islands are parallel are not, either in the eastern or western hemisphere, parallel to the chief axis of elevation. In the Old World this is very apparent, and is exactly accordant with another very striking fact already mentioned (§ 40), namely, that, while the direction of the belt of high land is nearly east and west, all the projections of land towards the sea, and all the chief promontories and peninsulas, run out almost due south. At present, the meaning of this apparent discordance can be only suggested as worthy of careful notice—the explanation may appear hereafter.

79. It only now remains to consider the results of these investigations with regard to the forms of matter upon the earth. It might be, and has been, inferred, from the relative proportion of the elementary substances present at the surface, their ordinary combinations, and a multitude of other facts well known, but which it has not been possible to refer to in this brief survey of existing nature, that all we can discover consists of a mere oxidized film—a crust formed on the cooling of a mass of matter once existing in a state of igneous fusion. This is the most natural and the first theory of the earth, suggested when a certain amount of general knowledge is brought to bear on a group of phenomena of enormous extent and complexity; but whether such view is sound, whether, indeed, we can thus at all explain many actual appearances consistently with known facts of other kinds, it still remains to determine. We shall not here pursue this subject further, but defer till a future chapter the general considerations which the investigation is calculated to suggest. This "igneous theory" has been adopted and supported by almost all the most eminent of modern geologists and physical geographers; but still we venture to call upon the reader to suspend his judgment on the matter till he has learnt the facts.

CHAPTER IV.

ON ATMOSPHERIC AND OCEANIC CURRENTS, AND ON CHANGES OF THE TEMPERATURE AND ELECTRICAL CONDITION OF MATTER AT THE EARTH'S SURFACE.

80. We have hitherto been considering the condition of matter forming the earth's crust, as presented in a certain definite shape at a given instant. We have also considered certain forces which may be regarded as causes of change, but nothing has been said of change itself; and in advancing to this, which is perhaps the most important department of Physical Geography in relation to Geology, we shall find it convenient to recognise changes of two kinds: the one, a mere movement of particles without any modification of the mass, or the change of place observed by the particles of air and water when set in motion and seen in some mineral substances during decomposition; and the other, a distinct and mechanical alteration in the form or position of the solid matter, as induced by the rubbing, grinding, tearing up, and rolling or carrying along of earth, mud, or stones. In the present chapter we shall consider only the former kind of changes, and these no more than as they really affect the latter kind. In other words, we shall consider the air and water, and their movements, as agents of mechanical change in hard rocks.

81. The earth, constituted as we know it to be, and revolving round its own axis, and also round the sun, which is in some way an exciting cause of light, heat, chemical action, and electricity, the different parts of the surface are exposed periodically to the action of these rays; and as different substances and different forms of matter are variously acted upon by the same amount of exposure, there is constantly a circulation of the atmosphere produced, accompanied by heat, and conveying along not only heat, but a large quantity of moisture, over the earth. There is also a regularly alternating exposure to the stimulus of light, and a similar daily and even hourly change in the electric state of the air and earth. The mutual action of these changes, and causes of change, complicates so greatly the actual phenomena of what is called *weather*, that it is proverbially the thing of all others least to be depended on, and in most temperate climates has come to be regarded as governed by no laws yet ascertained, and affording no appearances by which we can predicate future consequences. Perhaps the simplest and most satisfactory method to adopt in this place will be, first, to discuss the relations of the atmosphere to water, or the appearances sometimes called *aqueous meteors;* then,

the movements of the air, especially those chiefly referable to simple and known causes; and, lastly, the results of the movement of masses of air differently charged with aqueous vapour, and in different electrical conditions, when either impinging upon other masses of air or moving over irregular surfaces of land. Under these three heads may be brought most of those facts of meteorology, the knowledge of which is essential to the geologist.

82. The atmosphere presents a mixture of gases, of which oxygen and nitrogen form the principal part; but, although the proportions are nearly invariable, the gases do not form a definite chemical compound. It may be considered, that pure dry air contains in 100 parts by weight,* 23 parts of oxygen, and 77 parts of nitrogen gas, the proportion hardly varying to the extent of one per cent. under any known circumstances. Ordinary atmospheric air contains, in addition, about five parts in ten thousand of carbonic acid and carburetted hydrogen gases, besides a very variable, and often rather considerable, proportion of aqueous vapour, and other substances, which are usually regarded as impurities, but some of which, as ammonia, seem very essential to vegetation, and are probably always present.

83. The air being highly elastic, its density is greatest at the earth's surface, and at the height of about $2\frac{3}{4}$ miles (11,556 feet) the density is halved, or one volume is expanded into two, so that at such an elevation the barometer (which measures the density of the air, by finding the length of a column of mercury effecting the same pressure, or balancing the pressure of the air) only shows a height of one half that which it showed near the sea-level. The density is again halved at about every 12,000 feet of additional elevation, and at an altitude of 45 miles the air would scarcely exhibit any sensible density. It probably extends much further, but is certainly limited, as, at the height of about three diameters, or 24,000 miles, the centrifugal force would counterbalance the force of gravity.

84. If the atmosphere were everywhere of the same density as at the earth's surface, its height under ordinary conditions, the barometer standing at 30 inches, would be about 5·208 miles (26,500 feet); and as 100 cubic inches of air, deprived of aqueous vapour and carbonic acid, at the temperature of 60° Fahr. and under pressure of 30 inches of mercury, weigh 30·83 grains, we can determine the weight of the whole body of pure dry air to be about 4,845,210,000,000,000 tons.

But in estimating the mass of the atmosphere, we must also take into account many other substances generally present. Thus there is a certain amount of aqueous vapour, very variable in different places, but measurable on a general average. So, also, there is a sensible proportion of carbonic acid, carburetted hydrogen and am-

* The following is the composition of dry air by volume; the proportion of aqueous vapour being too variable to be worth inserting:—

Nitrogen	7912	10,000
Oxygen	2080	
Carbonic acid	4	
Carburetted hydrogen	4	
Ammonia	Trace.	

GRAHAM'S "Chemistry," second ed. p. 336.

monia, and a trace of many other substances. These altogether will appear as follows, separating the oxygen and nitrogen, and estimating the absolute weight in tons:—

	Weight in tons avoirdupois.
Nitrogen	3,750,813,700,000,000
Oxygen	1,094,396,300,000,000
Water	50,000,000,000,000
Carbonic acid	3,037,200,000,000
Carburetted hydrogen	1,000,000,000,000
Carbonate of ammonia	250,000,000
Various substances	50,000,000
Total	4,899,247,500,000,000 tons.

Under the last head, "various substances," are included sulphuretted hydrogen, sulphurous, sulphuric, hydrochloric, and nitric acids, the odoriferous principles of plants, the miasmata of marshes, various gases liberated in manufactories or by volcanoes, besides potash, soda, lime, magnesia, iron, manganese, &c. The estimate of the quantity of water is very doubtful, but is based on the only calculations that have yet been made.

85. It is owing to the chemical condition of the air, as a mixture of dry gases with aqueous vapour, and to the never-ceasing changes in temperature and electrical state thus induced, that we owe the most remarkable of its phenomena. It is, however, well ascertained that, notwithstanding the constant absorption of many of its parts by organized beings, often to an enormous extent, the relative proportion of the principal gases is very permanent, as air taken from various parts of the earth, and from various altitudes, has been found to present no appreciable differences in this respect. The quantity of oxygen varies slightly in different seasons, and is rather larger near the surface over the sea than on land.

86. Humboldt* has mentioned as the principal features of a general descriptive picture of the atmosphere, 1st. Variations of atmospheric pressure; 2nd. Climatic distribution of heat; 3rd. the humidity of the atmosphere; and 4th. its electric tension. Under these heads it will be convenient to consider the facts that bear on Geology.

87. The pressure of the atmosphere is simply the gravitation of the whole mass of matter of which it is made up to the whole mass of the earth. On an average of years it is the same in similar climates at equal distances from the surface, but exhibits many periodic and temporary oscillations. It becomes gradually less at greater heights, as the mass of the atmosphere which presses is there less. The pressure is the same in all directions, as that of any gas or fluid must necessarily be; and thus, though equivalent to about fifteen pounds on every square inch of surface, it is not felt unless the air on that surface is removed. The pressure has been hitherto most conveniently measured against a column of mercury or other fluid,

* See "Cosmos," Sabine's translation, first edition, vol. i. p. 307.

and it is found that about 30 inches of mercury, or 34 feet of water, balance that of the whole atmosphere.* When from any local or temporary cause of change on the same horizontal plane, or by any elevation above that plane, the pressure is altered, that of the column of mercury or water corresponding to it must be altered likewise; and thus the fluid in the barometer falls or rises as the pressure of the air diminishes or increases.† Careful and tabulated records of the nature and amount of barometric change exhibit three kinds of these oscillations, viz. diurnal, annual, and irregular. The daily oscillations present two maxima (one at about 9 h. A.M., and the other about $10\frac{1}{2}$ h. P.M.), and two minima (at about 4 A.M. and 4 P.M.), which within the tropics are attained with almost perfect regularity, undisturbed by storm, tempest, rain, or earthquake, at all elevations from the level of the sea up to 13,000 feet. Towards the poles, and at great elevations in temperate climates, this regularity is diminished, and at length lost, or even perhaps inverted. The amount (or amplitude) of the oscillations varies greatly, but is most considerable near the equator, amounting there to about $\frac{1}{10}$th of an inch.

88. The second kind of barometric oscillation is that observed during the successive months of the year. In warm climates north of the equator the mean pressure diminishes gradually from winter to summer throughout the year, on the east coast of the great continent from December to June, in India and at Cairo from January to July, and in the West Indies from January to August, the range being about 0·63 inches. In the north temperate zone there are two minima, one near the time of each equinox, the summer maximum being, however, lower than that of winter.

89. The irregular oscillations of the barometer are far less readily explained and described than those periodic ones we have been considering. They depend on certain winds, on geographical position, on the fall of rain, and on the electric tension of the atmosphere. The former conditions will be best understood by reference to the subjoined table of the mean barometric pressure under different winds in the neighbourhood of London; and although anomalies sometimes occur, especially in the interior of continents, it may be concluded that the barometer is generally highest, *cœteris paribus*, when

* Regarding the atmosphere as a mixture of gases, the nitrogen gas exerts a pressure equivalent to

Nitrogen gas	23·36	inches of mercury
Oxygen gas	6·18	,,
Aqueous vapour	0·44	,,
Carbonic acid gas	0·02	,,
Total	30·00	

† In the so-called *aneroid barometer* (a barometer without fluid), the pressure of the air is measured by the elevation or depression of the surface of a closed metallic vessel exhausted of air. The pressure of the air being marked at a given time, any alteration is indicated by the movements of the surface, and communicated by wheels marking the change on a dial by an index.

winds blow from the pole, and from the interior of continents, and lowest when they come from the equator or from the sea.

A table of this kind is called the *barometric wind-rose* for the place in question. The following is the barometric wind-rose for London :—

North	29·890	inches.
North-east	29·949	„
East	29·879	„
South-east	29·796	„
South	29·700	„
South-west	29·734	„
West	29·814	„
North-west	29·844	„
Mean	29·826	inches.

90. Geographical position, or position with reference to the vicinity of the sea, wide tracts of desert, lofty mountains or extensive plateaux, produces great modifications in the pressure of the atmosphere, and therefore in the height of the barometer, so that the total mean amplitude or range of the barometer during the whole year, or the summer and winter halves of the year, varies extremely in different districts, being greatest, so far as observations show, in Iceland, where the annual range amounts to 1·4137 inch, and smallest at Batavia, where it is only 0·1173 inch. It will be understood that the actual range on particular occasions is often very much greater than these figures show, the winter range being generally higher than the summer.

91. The temperature of the atmosphere is greatest at the earth's surface in any district, and diminishes at the rate of about 1° Fahr. for every 350 feet of elevation near the earth, but not so rapidly at great altitudes. At a certain height, however, the region of perpetual congelation is reached in every climate ; and if the mountains are sufficiently lofty this is manifested by their snow-capped summits in the middle of summer. Generally the snow line, as this limit is called, is at the height of 15,000 feet at the equator,* 3800 feet at 60° latitude, and only one foot at 75°, but there are infinite local modifications of the general law, one of the most striking occurring in the Himalayan mountains, where the snow lies on the southern declivity at about 15,000 feet, although on the northern, which might have been expected to show the coldest temperature, it is not met with till we reach 20,000 feet. The causes of this decrease of temperature in the upper parts of the air are, 1st, that the air in these regions is expanded, and the quantity of heat in a given area near

* In South America, according to Pentland, the snow line, which is about as high as the summit of Mont Blanc (15,750 feet) at the equator, actually ascends more than 2500 feet as we advance southward until it attains the maximum elevation of nearly 18,500 feet not far from Quito.

the surface is, therefore, distributed over a much larger area as we ascend; and, 2nd, that a great part of the heat of the atmosphere is obtained by contact with the earth's surface, the sun's rays being absorbed but little while merely passing through the air. The temperature of the air, as dependent on that of the subjacent earth, varies, of course, according to climate and season.

92. The condition of the atmosphere with regard to moisture varies very greatly at different hours and seasons, and in various places; but we may consider generally that dry air of a given temperature is capable of holding in suspension a certain limited quantity of aqueous vapour, and that when the temperature is diminished the capacity for retaining water is also diminished. When, therefore, warm air fully charged with vapour comes in contact with a cold surface, or with a cold stratum of air, it is chilled, and part of its vapour must be precipitated; either as dew on some solid substance present to receive it; or in small drops or globules of water often still retained in the form of visible vapour, either as mist or fog; or else as clouds wafted along by winds, and depositing their load at a great distance from the spot whence it was evaporated. It may well be supposed that over the sea and large fresh water lakes the air is always in a state of saturation. On coast lines also it remains almost fully charged with moisture, but in the interior of continents the conditions are often very different; so that there are some districts having seasons of incessant rain, others where rain may fall at any time, and others again where no rain falls, and where the air is, therefore, invariably dry. The air at the surface, especially in temperate climates, is, however, by no means always in the same state as that a few hundred feet above; and the meeting of two currents high in the heavens will often produce a change not indicated by instruments or appearances near the earth.

93. The quantity of water distributed over the earth's surface after being conveyed through the air in clouds is very large; far larger, indeed, than could be supposed without careful investigation. It is the actual quantity of rain falling in a given time that enters into such calculations, and for the purpose of measuring its amount various instruments have been contrived. These show, 1st, that while mountain districts on the whole receive a larger quantity of rain during the year than plains, yet in any place of moderate elevation more rain falls near the surface than above it; 2nd, that a larger quantity falls on coast lines on the western side of great continents in the temperate zones than on the eastern side or the interior, but in the tropics more on the eastern side; and, 3rd, that more rain falls in tropical than in temperate climates, though the number of days on which rain falls is greater in the latter, than the former, case. In the tropics, even in the rainy

season, the rain falls chiefly during the day; but in temperate climates, indifferently by day or night.

94. Within the tropics there is a rainy and a dry season; and in the tropical countries of the New World the mean annual fall is about 115 inches, while in the Old World it is not more than 76 inches, giving a general mean for the tropics of 95½ inches. In the temperate zone of the northern hemisphere there is less difference between the eastern and western continents, the mean being 37 inches, but the extremes in each case exhibit very wide ranges. In the south temperate zone the fall averages 26 inches only, and in the frigid zones it has not been measured with sufficient accuracy, but is very much smaller. It would appear that between three and four times the total quantity of water retained at one time in the atmosphere in the form of invisible aqueous vapour or cloud, falls annually on that portion of the earth's surface marked by the presence of land; a striking proof of the frequency of change in the condition of the atmosphere in this respect, and the rapid transmission of aqueous vapour through it.

The following table will give the distribution and absolute quantity of water falling on the land in different districts of the earth according to the latest and best estimates. It must be understood that in the two frigid zones, and, indeed, in the temperate zones, the estimate includes the whole fall of water whether as rain or snow:—

	Area of land in sq. ms.	Total annual rain-fall in cubic feet,	in tons weight.
N. and S. Torrid zone	19,400,000	4,282,750,000,000,000	119,177,000,000,000
N. Temperate zone..	25,150,000	2,160,500,000,000,000	60,000,000,000,000
S. Temperate zone ..	4,350,000	261,500,000,000,000	7,275,000,000,000
N. and S. Frigid zone	2,600,000	70,250,000,000,000	2,000,000,000,000
General total....	51,500,000	6,775,000,000,000,000	188,452,000,000,000

95. The electric tension of the atmosphere is constantly undergoing great disturbance, being affected by every change in its humidity and temperature. The phenomena of storms, not merely of thunder, but of rain and wind, are intimately connected with, and dependent on, these modifications. Even the deposit of dew, the gentlest of atmospheric changes, as well as the formation of mists, fogs, and clouds, and the falling of rain, snow, and hail, must be regarded as both consequent upon and causing great electric disturbance. When serene the atmosphere almost always indicates positive electricity.

96. Violent storms occur frequently in the tropics, and are called hurricanes, tornados and typhoons, but they are generally much limited in extent and direction. They advance from one point with a powerful and rapid gyratory motion combined with a direct progress; but while the latter is often not more than eight or ten miles an hour, the former is sometimes 50 or 60 miles, or even more, producing destruction in the course of the storm from the irresistible

force acquired by such extreme rapidity. All of them are referable to electrical changes, which have been generally induced by great and unequal distribution of heat. (See § 103.)

97. Winds or currents of air are produced whenever the atmosphere is set in motion, in consequence of one part being displaced by some local cause and another part rushing in to supply the vacant place. Winds keep the atmosphere permanently in a state of complete mixture of the component parts. They help to purify it by removing miasma and exhalations locally injurious, but admitting of such dilution as to be ultimately harmless :—they favour and assist in the fecundation of plants by the distribution of pollen : —they modify and equalize the temperature of various parts of the surface :—they convey clouds, and thus distribute moisture, and render the interior of continents fertile ; but sometimes they carry with them poison and death, for they bear along the insects and the blight that often destroy the hopes of the husbandman, and the fever that baffles the skill of the physician.

98. Generally if two districts are unequally heated a cold wind will set in near the surface from the less heated to the more heated district, while a corresponding current in the opposite direction takes place in the upper regions of the atmosphere. Thus, when the sun shines during the day, and land and water are equally exposed to its influence, the land is more heated than the water, and a cool breeze is soon felt setting in landwards ; while in the evening when the sun has set, and the greater radiation cools the earth sooner than the water, the converse takes place, and in this way is readily explained the phenomena of land and sea breezes, and the numerous apparent anomalies observed in local prevalent winds.

99. The trade-winds are likewise periodical winds, occurring near the tropics in the open ocean. The portion of the earth near the equator is the hottest part of the globe, and the air over it is therefore more heated than elsewhere, while on the other hand the regions near the poles are exposed to perpetual cold. There is thus induced a constant cool current near the earth, setting southwards from the north pole, and northwards from the south pole, and constant warm currents above this cooler one, proceeding from the equator towards each pole. These would be distinctly observable everywhere, but for the revolution of the earth round its axis from west to east, which alters such currents, and produces a tendency to north-east winds in the northern, and south-east in the southern hemisphere. But now comes into play another result of the condition of the atmosphere, for the wind advancing along the surface from the poles northwards or southwards, must, as it approaches nearer the equator, arrive successively at points which

move more rapidly than itself, as the air at the equator and poles, in each case, moves once round the earth in every twenty-four hours, but near the poles the circle of its motion is very small, while at the equator it is enormously larger. Thus it results, that at certain latitudes the winds blow constantly from the east, instead of north-east, and this direction is pretty uniform between the twenty-eighth parallel on each side of the equator, except that near the equator (between the third and ninth parallels of north latitude) there is a region of calms and variable winds, alternating often with violent storms.

100. The north-east trade-wind is less steady in the Atlantic than the south-east, probably because of the more confined condition of the northern part of that ocean. In the Pacific this wind does not seem to extend beyond about 140° west longitude, that is as far as there is open sea. The multitude of islands and coral banks in the rest of that portion of the tropical sea, and the land of the great continents, both in the Old and New World, preventing these regular winds from being perceived, and introducing a multitude of local and distinct currents.

101. The trade-winds, interrupted in their course by the distribution and form of the land in the Indian Ocean, pass there into periodical winds called *monsoons*, which blow from the middle of April to the middle of September in one direction, and from the middle of October to the middle of March in the opposite direction. North of the equator the former are south-west, and the latter north-east winds, and south of the equator the summer monsoons are south-east, and those of the winter north-west. The change takes place gradually, beginning in the upper regions of the atmosphere and being often accompanied by storms. Monsoons of less perfect character occur on the coast of Brazil, in the Gulf of Mexico and elsewhere, and other periodical winds known by various names are common on most shores.

102. Beyond the limits of the trade-winds in the temperate climates of both hemispheres, wind more commonly blows from some one direction than any other, and every country has thus what are called *prevalent winds*. South-west and north-west winds prevail near the surface in the north and south temperate zones respectively, and in each case there are return-currents in the upper regions of the atmosphere.*

103. Storms of the nature of hurricanes are rarely met with beyond the torrid zone, and they chiefly occur or commence near the tropics. In the northern hemisphere, the region of the West Indies, and in the southern, the south-western part of the Indian Ocean,

* The mean direction of the wind deduced from various observations in the north temperate zone is thus stated by Kämtz :—England S. 66° W.: France, S. 88° W.; Germany, S. 76° W.; Denmark, S. 62° W.; Sweden, S. 50° W., Russia, N. 87° W., and North America, S. 86° W.

or rather the islands there situated, are the principal foci whence have proceeded the most violent storms on record. They move on the north side of the equator from east round by the north point of the compass to west (from right to left), and in the southern hemisphere in the opposite direction (from left to right). In the former district the storm season is in the autumn months, extending through August, September, and October, and including, though rarely, June and July. The storms range from latitude 10°, to 50° north, and longitude 50° to 100° west. In the Indian Ocean they prevail chiefly from December to April, occurring also, though seldom, in May or November, and in that part of the world they range from the coast of Madagascar to that of Australia. The ordinary hurricanes seem to extend over a breadth of from 500 to 1000 miles in the Atlantic, and of about 600 miles in the Indian Ocean. Storm waves and temporary currents (storm-currents) seem often to accompany a hurricane at sea, the former being true waves raised above the level of the sea, and carried along with the storm in its onward course, and the latter consisting of a rotating stream in the centre of the storm. Torrents of rain and explosions of thunder, with vivid flashes of lightning, have been generally observed to accompany hurricanes. The typhoons of the China sea have the usual range of latitudes for storms (10° to 50° N.), and extend from the coast of China to longitude 150° east. They occur only once in about three or four years. The deserts of Asia and Africa, some of the plains (llanos) of South America, and part of Australia, are exposed at times to hot stormwinds, which are of the nature of tornadoes, and are very destructive.

104. By CLIMATE (as Humboldt has expressed in his Cosmos, vol. i. p. 312, English translation) we understand "all those states and changes of the atmosphere which sensibly affect our organs : temperature, humidity, variation of barometric pressure, a calm state of the air, or the effects of different winds, the amount of electric tension, the purity of the atmosphere, or its admixture with more or less deleterious exhalations, and lastly, the degree of habitual transparency of the air, and serenity of the sky, which has an important influence, not only on the organic development of plants, and the ripening of fruits, but also on the feelings and whole mental disposition of man." Many facts bearing on climate have been already touched on, and we have here chiefly to consider the modifications of it dependent on position, and the various changes (not merely possible but certain) that would ensue from an alteration in the absolute proportion of land and water, and the relative position and arrangement of the land that may at any time exist.

105. Climate in this sense is chiefly determined by averages of temperature, not only of the year, but also of the different parts of

the year. If lines are drawn through places in which the same quantity of heat is received annually, or in other words, in which the mean annual height of the thermometer* is the same, we shall find, that while pretty regularly parallel to the equator, and to each other, where it is possible to connect observations made at sea, still when we trace them over continents, they have little reference to latitude, but are modified by the form and position of the great masses of land, and the principal marine currents which we shall presently consider. If similar lines are drawn through places having the same mean summer or winter temperature, we shall here again find that a great divergence is presented, so that these three sets of lines are quite distinct from each other, and dependent not nearly so much on position with regard to the equator, or the poles, as on their position on the land, the vicinity of large level tracts, whether lofty or low, the neighbourhood of mountain-chains, of large rivers, or arms of the sea, or of the great ocean itself, and in a word with every physical feature of the earth, no matter what it be.

Climate has been found to depend chiefly, then, on matters totally independent of absolute heat as derived from the sun, and so much is this the case, that places in the same latitude on the east and west coasts of North America, in latitude 57°, show a difference of mean annual temperature amounting to 20° Fahr.; other places differing as much as 13° in latitude have the same mean annual temperature; and Dublin and Buda (Hungary), having the same mean annual temperature, exhibit a difference in mean temperature of one of the summer months (August), amounting to 9° Fahr., and a difference of 12° in mean winter temperature.

106. It results from such considerations, and from the very numerous facts observed in this department of science, that the total quantity of heat received upon the earth from the sun depends almost entirely on the circumstances under which the heat is received, for if the atmosphere were uniformly clear and dry at one time, and uniformly cloudy at another, the quantity of heat reaching the earth would vary enormously. So also if the land were all distributed in small islands, and not chiefly in great masses, the heat received would be immediately distributed, and an average or

* This well-known instrument measures temperature and changes of temperature by the expansion of a column of fluid (mercury or spirits of wine), to which a graduated scale is affixed, and observations being made at different hours of the day for every day in the year, and carefully recorded, we can readily obtain the mean daily, weekly, monthly, or annual temperature, or the mean temperature for the summer and winter seasons. The averages of a number of years' observation being taken the result becomes of great value for comparison. The thermometer-scales in common use are, 1. That of *Fahrenheit;* where the space or expansion of the fluid that occurs between the freezing and boiling point of water is divided into 180 equal parts called degrees, and the commencement of the scale is 32 of such degrees below the freezing point, so that the boiling point of water is 212.° This is the scale commonly used in England. 2. The *Centigrade* or *Celsius* scale, where the space between the freezing and boiling points of water is divided into 100°, and the zero point is the freezing point of water, and, 3. The *Reaumur* scale where the zero is the same as in the Centigrade, but the space between the freezing and boiling points is divided into 80°.

insular climate would prevail everywhere. If the land were all in very lofty masses at one time, and all in low plains at another, the temperature attained must again differ to a very wide extent, being least in the former case and greatest in the latter. And if, lastly, the land were all collected towards the equator at one period, and all thrown towards the poles at another, the temperature would again exhibit vast changes, the maximum being attained in the former case, and the minimum in the latter. That the land is distributed as we now find it, does not seem to be the result of any abstract necessity, and it would seem perfectly consistent with all known laws and all existing causes, if it either had formerly, or should have hereafter, a totally different distribution, and rise above the water in proportions altogether unlike the present. Sir Charles Lyell has illustrated and enlarged on these possibilities in the seventh chapter of his "Principles of Geology," and the reader is referred to that work and to the Essays of Humboldt, for many important views bearing upon the subject.

107. Lines joining places having the same mean annual temperature, the same mean summer, and the same mean winter temperature are called respectively *isothermal*, *isotheral*, and *isochimenal* lines (from the Greek words *isos*, equal, *thermos*, heat, *thēros*, summer, and *cheimōn*, winter). The former (isothermals) are those most generally regarded as important; but the latter are also extremely influential in governing and limiting the ranges of vegetable and animal life, and the profitable growth of various plants valuable to man. Thus the vine requires great heat in summer, but can endure extreme winter cold; so that it produces rich and valuable wine in Hungary, but hardly ripens in Dublin, its limit of mean summer temperature being above that of the coast of Ireland. The limits of the profitable growth of the vine are the isothermal of 50°, the isotheral of 65°, and the isochimenal of 33° Fahr. It will, of course, be understood that we are here speaking of heights not greatly above the sea-level, as elevation diminishes the temperature in all cases.

108. The following table, copied from Martins' translation of Kämtz, will give a general outline of the conditions of mean annual temperature on the two sides of the Atlantic:—

Mean annual temperature or Isothermal.	Latitude on American coast.	Latitude on European coast.
25° C = 77° Fahr.	24° 21′	18° 49′
20° „ = 68° „	32° 20′	31° 27′
15° „ = 59° „	38° 24′	41° 33′
10° „ = 50° „	41° 30′	52° 3′
5° „ = 41° „	44° 51′	60° 7′
0° „ = 32° „	51° 57′	66° 48′

109. It has been attempted to determine approximately the mean annual temperature of particular portions of the land. Thus the temperature of the tropics generally on the coast is considered to amount to 81½° Fahr., but in the interior it is generally higher. The temperature of the north pole has in like manner been estimated, Arago having calculated that the land, even if surrounded by water, cannot possess a mean heat so high as the zero of Fahrenheit. But it is likely that this estimate is too low, and that the real temperature is nearly 17½ ° Fahr. The temperature of the south pole is probably much lower. Lastly, the mean temperature of the whole surface of the earth has been found by Dove to be 58·2° Fahr., being about 54° in January and 62° in July.

110. Attempts have been made to determine the equator of heat and the poles of cold. The former is not very satisfactorily made out; but with regard to the latter there are probably two such points in the northern hemisphere, one being in America and another in Siberia.

111. Below the surface of the earth, to a certain small depth, the temperature of the rock rises and falls slowly in accordance with the changes that take place at the surface itself, but at a depth varying from a few inches to 40 feet the range becomes scarcely perceptible. There is thus at a certain depth a stratum of invariable temperature, and below this any increase that is observed must belong either to heat actually present in the interior, or to heat absorbed gradually at a former period of the earth's existence, or else to chemical changes now going on. It has been usual to assume the former igneous fluidity of the earth as a sufficient and ready explanation of this and some other phenomena, indicating a present high temperature at small depths; but whether all the other possible causes have been fairly considered may, perhaps, be doubtful. The fact, however, is an important one that, for such moderate depths as we are able to attain by artificial means, there seems a regular rate of increase.

According to Boussingault's researches, the stratum of invariable temperature within the tropics in South America is not more than a foot or two; but, by observations made at Trevandrum by Mr. Caldecott, in 1842 and 1843, the temperature there varies greatly even at the depth of six feet. In latitudes 48°—52° N., the depth of the stratum varies from 60 to about 64 feet.

112. The motion of water in the sea, and the circulation of that most important fluid over the earth and within its external crust, are subjects not at all less interesting and important than those concerning the gaseous covering of our globe just treated on. The movements of water on a large scale are principally by tidal waves and marine currents; but in considering the circulation of water we must introduce the subject of springs, and the disposal of that portion of the rain that falls on the earth, which is neither conveyed along by rivers to the ocean nor taken back by evaporation into the atmosphere. Each in turn will require attention, but first of all it is desirable to give some definite notion of the nature of *waves*, a term commonly used in speaking of certain kinds of motion, but of which there are very different kinds.

113. When the surface of a disturbed sea is carefully looked at, the various tumultuous tossings may be grouped into a number of definite forms, and any such form to which we can individually refer, we call a wave. Some of these appear to be rushing on at the rate of many miles an hour; but if a ship is upon them they appear to pass under it, lifting it, but not causing its progression. And in this way also it is clear that the motion of a wave may be different from the motion of the water in which it moves, for we often find waves coming in towards the shore with great distinctness, rapidity, and violence, while the tide perhaps is ebbing, and pieces of wood are being gradually floated out.*

't motion The true nature of a wave may be discovered by taking a long, narrow trough, filled with water to the depth of a finger length,

* In this account of waves—a subject of extreme importance to the geologist—I have chiefly availed myself of the memoir by Mr. Scott Russell in the "Report of the Meeting of the British Association for 1844," p. 311, *et seq.*

and disturbing the water by moving the hand for a short time along the channel, thus pushing along to some distance the fluid which the hand touches, and suddenly stopping. But, the original motion being stopped, the movements in the water are by no means stopped also. A temporary heap is formed, rising above the former surface, which appears to travel onwards for a great distance, and which results from the crowding of particles to occupy a new place. This is a *wave.* The rate of displacement of one series of particles by another is called the *velocity of transmission* of the wave. The shape assumed by the crowded particles is its *form,* and the distance (in the direction of transmission) to which the crowding extends is its *length* or *amplitude.* Its height is to be reckoned from the highest point or crest to the original surface of the fluid.

"Such being the wave and its motion, the water motion is altogether distinct. Let us select from the crowd of water-particles an individual, and watch its behaviour during the migration. The progressive agitation first reaches it while still in perfect repose; the crowd behind it push forward, and new particles take its place. One particle is urged forward on that before it, and being urged on from behind by the crowd still swelling and increasing, it is raised out of its place and carried forward with the velocity of the surrounding particles; it is urged still on, until the particles which displaced it have made room for themselves behind it, and then the power diminishes. Having now in its turn pushed the particles before it along out of their place, and crowded them together on their antecedents, it is gradually left behind, and finally settles quietly down in its new place. Thus, then, the motion of migration of an individual particle of water is very different from the motion of transmission of the wave.

"The wave goes still forward along through the channel, but each individual water-particle remains behind. The wave passes on with a continuous uninterrupted motion. The water-particle is at rest, starts, rises, is accelerated, is slowly retarded, and finally stops still. The range of the particle's motion is short, but its translation is interrupted and final. Its vertical range and horizontal range are finite. It describes an orbit or path during the transit of the wave over it, and remains for ever after at rest, unless when a second wave happens immediately to follow the first, when it will describe a second time its path of translation, passing through a series of new positions or phases during the period of the wave. The motion of the particle is not, therefore, like the apparent motion of the wave, either uniform or continuous. The motion of the water-particles is a true motion of translation of matter from one place to another with the velocity and range which the senses observe. But the wave-motion is an ideal individuality attributed by the mind of the observer to a process of changes of relative position or of absolute place, which at no two instants belongs to the same particles in the same place. The water does not travel, the visible heap at no two successive instants is the same. It is the motion of particles which goes on, now at this place, now at that, having passed all the intermediate points. It is the crowding motion alone which is transmitted. This crowding motion transmitted along the water idealised and individualised is a true wave.

"Wave propagation therefore consists in the transmission from one class of particles to another, of a motion differing in kind from the motion of transmission. Wave-motion is, therefore, transcendental motion; motion in the second degree, the motion of motion, the transference of motion without the transference of the matter, of form without the substance, of force without the agent.

"It is essential to the accurate conception and examination of waves, that this distinction between the wave-motion and the water-motion be clearly conceived. It

has been well illustrated by the agitations of a crowd of people, and of a field of standing corn waving with the wind. If we stand on an eminence, we notice that each gust, as it passes along the field, bending and crowding the stalks, marks its course by the motion it gives to the grain, and the visible effect is like that of an agitated sea. The waving motion visibly travels across the whole length of the field, but the corn remains rooted to the ground." *

115. There are thus two classes of elements in wave-motion, and various kinds of motion in water consequent upon them. The waves vary in form, in their being elevated above or depressed below the plane of repose, in the rate at which they are propagated, in their existence in single waves or groups, in the actual transmission or mere oscillation of the water, and, lastly, in the sources from which they arise.

116. Taking into account all the principal phenomena of waves, there result several very different kinds. One kind is called the *wave of translation*, and involves the movement in mass of the whole body of the fluid from one place to another. Of this kind is the tide-wave, and any diluvial wave, or rush of water arising from a sudden addition of water, serving for the transmission of mechanical force. It is a solitary wave raised above the original fluid surface, and has a definite form and magnitude, and a uniform velocity, dependent only on the depth of the fluid and the height of the wave-crest. The total effect of having transmitted this wave along a channel is to have moved successively every particle in the whole channel forward through a space equal to the volume of the wave † divided by the water-way of the channel. During transmission the vertical arrangement of the water is not affected.

117. The other kinds of waves will not enter into any consideration of wave motion that we have to offer. They are 2. Oscillating waves, such as wind waves, ocean swell, and stream ripple. 3. Capillary waves, such as are seen when a gentle breeze disturbs the surface of water, and 4, Corpuscular waves, produced by the passage of sound through water. It may be well, indeed, to state, that the oscillating wave is the simplest of all in some respects, as in it the apparent motions of the water are identical with the actual paths of individual particles. It is the same as the standing wave of running water, or the wave produced in a current when it passes over some permanent obstacle. This wave has been observed to pass into a wave of translation in the case of breakers on a sea-shore.

118. We now come to the application of the wave theory to the tides, which may be understood to consist of a single wave of translation, often divided and broken, but retaining a general direction, and first given as the wave is originally formed, by the attraction of the moon and sun on the mass of the water as distinct from the whole mass of the earth. The direction is modified by the form of the land and the channels through which the original wave passes.

* Report on Waves, by J. Scott Russell, Esq., Reports of British Association for 1844, p. 315.
† The number of particles which at any one time are out of their place constitute the volume of the wave.

Much difficulty has been felt in fully explaining all known phenomena on this subject, but we may regard the great tide-wave as only seen in its simplicity and immensity in the open sea of the southern part of the southern hemisphere. One part of this great wave advances up the narrow channel of the Atlantic, where it is in many places multiplied several times beyond its normal amount, and delayed many hours beyond its time by the peculiar configuration of the land. Another part moves in a similar way in the Pacific; and though almost dissipated, probably because of the equatorial belt of shallow coral sea, near the equator, on the Asiatic side, it continues to exhibit itself, though of very small amount, and chiefly along the western American shore. The mean height of the true tide-wave is not more than a very few feet, but the height sometimes reached, in consequence of interruptions, is more than seventy feet. The tide is reproduced in periodical oscillations of rather more than half a day.

119. "The Antarctic is the cradle of tides. It is here that the sun and moon have presided over their birth, and it is here also that they are, so to speak, abandoned to the guidance of their own congenital tendencies. The luminaries continue to travel round the earth (apparently) from east to west. The tides no longer follow them. The Atlantic, for example, opens to them a long deep canal, running from north to south; and after the great tidal elevation has entered the mouth of this Atlantic canal, it moves continuously northwards; for the second twelve hours of its life it travels north from the Cape of Good Hope and Cape Horn, and at the end of the first twenty-four hours of its existence, has brought high water to Cape Blanco on the west of Africa, and Newfoundland on the American continent. Turning now round to the eastwards, and at right angles to its original direction, this great tidal wave brings high water, during the morning of the second day, to the western coasts of Ireland and England. Passing round the northern Cape of Scotland it reaches Aberdeen at noon, bringing high water also to the opposite coasts of Norway and Denmark. It has now been travelling precisely in the opposite direction to that of its genesis, and in the opposite direction, also, to the relative motion of the sun and moon. But its erratic course is not yet complete. It is now travelling from the northern mouth of the German Ocean northwards. At midnight of the second day it is at the mouth of the Thames, and it is not till the morning of the third day that this wave fills the channels of the Thames, and wafts the merchandise of the world to the quays of the port of London. In the course of this rapid journey, the reader will have noticed how the lines in some parts are crowded together closely on each other, while in others they are wide asunder. This indicates that the tide-wave is travelling with various velocity. Across the Southern Ocean it seems to travel nearly 1000 miles an hour, and through the Atlantic scarcely less; but near some of the shores, as on the coast of India, as on the east of Cape Horn, as on the east of the American Isthmus, as round the shores of Great Britain, it travels very slowly; so that it takes more time to go from Aberdeen to London than over the arc of 120°, which reaches between 60° of southern latitude, and 60° on the north of the equator. These differences have still to be accounted for; and the high velocities are invariably found to exist where the water is deep, while the low velocities occur in shallow water. We must, therefore, look to the conformation of the shores and bottom of the sea as an important element in the phenomena of the tides."*

120. The tide-wave is probably a very effective force with reference to the sea-bottom, and the transport of solid matter in deep

* Johnston's Physical Atlas, B. 4.

water. Being a wave of the first order, its velocity is far greater in deep water than in shallow, and if it proceeded with uniformity and regularity, the velocity at a depth of one fathom being eight miles an hour, at the depth of ten fathoms it would travel as much as 25 miles in the same time; at fifty fathoms 57 miles; at 100 fathoms 80 miles; at 1000 fathoms 250 miles, and at 4000 fathoms 500 miles.*

121. It is not necessary here to describe the inequalities of the tide-wave, or its height as affected by the figure of the shores or the form of the bottom. These details would be out of place in the present brief outline, but the geological student should be prepared to recognise the subject as having important reference to former or present modifications of the earth's crust; and for this reason we have presented here many facts and their causes that have not hitherto been introduced as part of geology. The mechanical force of the tide-wave must be extremely great, for it is absolutely incessant, and a repeated application of the same kind of action on a sea-bottom or coast line cannot fail to produce, in time, vast changes, although the nature and extent of these will depend entirely on the original form and extent in which the land first undergoes elevation, and the form and extent of the adjacent land. It is impossible to impress upon the student too strongly or too frequently the infinite importance of attending to what is now going on in nature, in order not merely to illustrate and account for, but to understand the true condition of the earth's surface, and its reference to the materials of which it is built up, and their mechanical condition. Tidal action is one of those forces that has been often spoken of in this respect, but is hardly yet estimated; and if by any statements of this kind we can connect physical sciences so directly bearing on each other, a great step will have been made towards giving a proper direction to geological study.

122. The next kind of movement that takes place amongst the waters of the ocean is that commonly designated by the term "*marine current.*" Marine currents differ from the ordinary modifications of the tide-wave most completely, and have been described by Humboldt as resembling rivers, of which the adjacent undisturbed masses of water form the banks, the line of demarcation being often shown where long bands of seaweed are borne onward by the current, and enable us to measure its velocity.

123. Currents are, however, of two very distinct kinds, *drift* and *stream* currents; the former resulting from the action of prevalent winds on the surface of the ocean, impelling it to leeward, until it meets some obstacle, over which the water becomes heaped. These currents are shallow, and rarely exceed in velocity the rate of half a mile an hour. They are produced chiefly in the regions of the trade

* See § 148, on the Mechanical Effect of Tidal Action.

winds and the monsoons, and they sometimes originate or assist stream currents, by heaping up the water against mud or sand-banks, coast lines, or stream currents already formed. A stream current is generally of considerable bulk, and is distinctly a wave of translation, caused by the tendency of water that is displaced to restore the equilibrium of the general surface of the ocean. It may have almost any depth or velocity; and many such currents are known, and at least partly traced. We proceed to enumerate some of the principal of them, but must refer to Major Rennell's "Investigation of the Currents of the Atlantic," Berghaus' "Physical Atlas," or Johnston's translation and English edition of the same great work, for more complete details.

It is usual to consider marine currents with reference to the oceans in which they chiefly appear, and thus some are regarded as Atlantic, others as Pacific currents, and some as belonging to the Indian Ocean. In fact, however, we can only understand these grand and influential phenomena by tracing them from their origin; and this is almost always at a great distance from their principal development.

124. Perhaps among the most important of the currents, though by no means the most striking, is the Equatorial current of the Pacific, which is supposed to commence in the Antarctic Ocean as a drift current, formed by the prevalent winds proceeding from the south pole towards the equator, moving at first steadily from the south but soon modified by local causes into a south-south-westerly wind. This wind conveys a large body of water, first towards the N.N.E., then N.E., and ultimately E.N.E., to between 30° and 50° south latitude. The great drift current thus produced is divided into several parts in about 100° west longitude, one portion forming a cold current along the coast of Peru; another a counter-current, returning southwards to Cape Hoorn; a third becoming an open sea current to the north-east; and a fourth turning westwards, so as to form the commencement of the great Equatorial current of the Pacific Ocean. Obeying the impulse of the trade winds, the water then runs with a permanent and steady flow towards the west, over a space of 50° of longitude, producing important results on the east coast of Asia, and throughout the vast area covered by islands, banks, and coral reefs between the main land of Asia and the south of Australia.

125. The Equatorial drift current thus heaping up water on the western verge of the Pacific continues to flow westwards, divided into several parts, in a number of true stream currents, some of them passing into the Indian Ocean, and becoming partially dissipated and modified by the south-east passage winds that prevail between lat. 12° and 28° south. An important portion of the water, however, crosses to Africa, and is there turned aside, passing between the island of Madagascar and the coast, and at length impinging against a great

South Atlantic counter current, when the water, prevented from proceeding southwards, passes round the Cape of Good Hope over the Agulhas Bank, by which it is lifted above its former level and brought into a condition to act forcibly on the waters of the Atlantic. The velocity of this current near the east coast of Africa varies, but is very considerable, its mean rate amounting to from 18 to 28 miles in 24 hours, but reaching sometimes to as much as $5\frac{1}{2}$ miles per hour. The breadth of the current is also very considerable, amounting to from 90 to 100 miles at the eastern extremity of the Agulhas Bank, where it is also very deep. A great part of this current returns eastwards into the Pacific, by what is called the Southern connecting current, but part of it proceeds into the Southern Atlantic current, and so into the main Equatorial stream current, which extends westwards for 3000 miles, from the coast of Africa to Cape St. Roque, the north easterly extremity of South America, and then north-westwards to the Caribbean Sea, an additional distance of 1800 miles. Its breadth is at first 180 miles, but it afterwards widens to 400 miles, and ultimately becomes more than 500 miles across. It moves with a mean velocity of about 30 miles per day, varying, however, from 25 miles in winter to as much as 60 miles in summer, between latitudes 16° and 23° west.

126. The Equatorial current thus conveys into the Caribbean Sea and the Gulf of Mexico, by the southern side, an immense volume of water, which must afterwards be discharged by the only open channel that exists in the northern part, namely, that between Florida and the island of Cuba. It issues thence as the *Gulf Stream*, and being at once deflected northwards by the islands and reefs of the Bahamas, it pours a vast volume of water, heated to the temperature of 86° Fahr., into the North Atlantic Ocean, at an average rate of 63 miles per day. The quantity has been estimated as more than three thousand times that discharged by the Mississippi, and is thus, no doubt, many times greater than the whole volume of fresh water poured into the sea from all the land on the globe. The waters of the Gulf Stream thus issuing, are bent round to the east by the form of the American coast line and the currents proceeding from the North Pole, and are conveyed across the Atlantic with a great velocity and high temperature, gradually but very slowly diminishing. The whole course taken by the water from the Florida coast to the Azores is about 3500 miles, which is performed in 78 days, at a mean rate of 38 miles per day. The stream traverses twenty degrees of latitude (from 23° to 43° north), and completely crosses the Atlantic.

127. "The maximum temperature of the Gulf Stream in the Strait of Florida is 86° Fahr., or about 9° above that of the ocean at the same latitude. At 10° farther north it is 83° to 84°, having lost little more than 2° in this space. At 63° west longitude it is 81° in summer, and nearly 67° in winter. Five degrees farther east it is 79°; at 50° west longitude it is 77°. Five degrees more to the east it is 75°, and at 40°

west longitude it is nearly 74°. Thus the temperature, like the velocity, decreases as the stream progresses, but not so rapidly, having lost only about 13° in 3000 miles; and even when it turns to the south, and spreads itself over the ocean, it still maintains the heat of summer. It cannot be doubted that this vast expanse of warm water, from 8° to 10° above the temperature of the sea, must have a great effect in mitigating the climate of the adjacent countries. A simple calculation will show that the quantity of heat discharged over the Atlantic from the waters of the Gulf Stream in a winter day, would be sufficient to raise the whole column of atmosphere that rests upon France and the British Islands from the freezing point to summer heat. It is the influence of this stream upon climate that makes Ireland the Emerald Isle of the sea, and clothes the shores of England with evergreen robes; while in the same latitude on the other side, the shores of Labrador are fast bound in fetters of ice. In 1831 the harbour of St. John's Newfoundland was closed with ice in the month of June, although it is 2° farther south than Liverpool; and the influence of the Gulf Stream is felt in Norway, and on the shores of Spitzbergen."*

128. Two currents commence on the eastern verge of the Gulf Stream; one (Rennell's current) running northwards, round the interior of the Bay of Biscay to the western coast of the British islands, at a velocity varying from 24 to 28 miles per day; the other proceeding southwards, originating opposite the coast of France, and continuing with a breadth of nearly 200 miles, its rate increasing from 12 to 50 miles a-day, till it turns eastward, along the coast of Guinea; after which turning again, it probably falls into the main Equatorial current. In part of its course it presents the singular phenomenon of two great oceanic streams (this and the Equatorial) running in parallel lines and almost in contact, but in exactly opposite directions.

129. The Arctic current of the Atlantic sets southwards and westwards from the Arctic Pole, originating, no doubt, in a drift current produced by prevalent winds; and in the same way there is an Antarctic Atlantic current proceeding eastwards from Cape Hoorn, and afterwards turning to the north. There are also some other currents of considerable importance, the most interesting being a branch from the Equatorial, proceeding south-westwards along the coast of South America, under the name of the Brazil current.

130. It appears, by careful reference to the currents known in various seas, that while these have all really originated in prevalent winds, and in causes totally independent of the present distribution of land and sea, they are so greatly modified by these conditions that all their effective value refers to them. Thus, if the entrance to the Caribbean Sea or the exit of the Gulf of Mexico had been on the Pacific instead of the Atlantic side of America, there cannot be a question that the climate and temperature of the Old World would have been extremely different from that which we now experience; and although no doubt the Atlantic is infinitely more important to European and American climates than the Pacific, still, any great

* Johnston's Physical Atlas, Div. B. i. p. 4.

modification of the latter ocean would not be without marked effect on the land all over the world.

If, at any former period of the earth's history, a complete barrier had existed to the entrance of the Equatorial current into the Caribbean Sea, the water might probably have been driven northwards along the American coast, warming the countries of North America; while the Arctic current, if slightly turned aside by changes in the position of the land near Greenland, might easily have acquired an easterly direction, bringing down ice-bergs, and even ice-fields, to the shores of England and France.

A small depression of the land in Western Europe would probably be accompanied by a great change of climate, but the nature and extent of the change would depend on movements at very distant points.

It is by no means an unprofitable speculation to consider the result of such modifications of the land, since, as we shall find afterwards, there is good evidence of change going on now, and also of changes effected within a period comparatively recent, tending to modify the form and distribution of the land in many parts of the world.

131. The depth of the great oceanic stream-currents is unknown, but in some cases it is certainly not less than 60 or 70 fathoms, and is probably much more. In these cases, as in that of the tide wave, the mechanical effect, especially when the stream moves with any degree of rapidity, must be very great at considerable depths. Owing to the slow rate of subsidence in deep water of small particles of matter not having a much greater specific gravity than water, it is certain that, over the whole range of a great current, deposits of mud, mingled with the remains of marine vegetables and animals in all imaginable degrees of admixture, may be in the course of formation, even where the surface water is clear, and the open sea shows but little organic life, either vegetable or animal.* The secrets of these great depths are not likely to be revealed for thousands or tens of thousands of years, but in times far distant they may be laid bare by the upheaval of the ocean floor, and land produced in tracts now quite unfathomable. The result will then have to be judged of from the appearances presented; but, unless the future naturalist is well acquainted with the laws that now govern these deposits, he will argue but very imperfectly concerning the history of what will be to him the past. The laws of nature, however, in these, as in other respects, are in all probability unchangeable, and thus we are right in studying existing phenomena, in order to learn the history of former events, and the early condition of the globe.

* Mr. Babbage ("Economy of Manufactures") has observed that if mud, mechanically suspended in water, sink through one foot of water in an hour, it will be carried by a current moving at the rate of three miles an hour to a distance of 1500 miles before it has sunk to the depth of 500 feet.

CHAPTER V.

ON THE EFFECT PRODUCED ON THE EARTH'S CRUST BY CHANGES OF TEMPERATURE AND VARIOUS ALTERATIONS OF CLIMATE AND ATMOSPHERIC CONDITION, AND BY ORGANIC AGENCY.

132. FROM changes in the actual state, the mechanical condition, and the mechanical position of the atmosphere and water, we pass on now to discuss how far these changes affect the more solid portion of the earth, or in other words, we have to consider the nature and effect of what is sometimes called *atmospheric and aqueous action.* This subject, however, has been already very ably handled by Sir Charles Lyell, in his "Principles of Geology," and chiefly confining his attention in that work to these and other possible and actual changes in existing nature, and enlarging greatly on such views of physical geography, he has presented to English Geologists a mass of facts and deductions exceedingly interesting, and showing a large amount of mechanical alteration involved in the working of existing laws, even during the very short period within the range of human observation. Some Italian and German authors, and among them Von Hoff* holds the highest rank, had also before, and have since, accumulated extensive materials of similar kind. The due consideration of these facts has led to the establishment of a school of observers and reasoners, not satisfied with the assumption of causes existing only in the imagination—supposed to elevate mountain-chains in a moment of time and sweep out valleys by waves of incalculable energy—but inquiring diligently concerning the true value of existing causes, especially when acting for a very long time and under favourable circumstances. The various facts bearing on the earth's history having thus been already well set forth, it will be necessary here only to recapitulate them briefly under distinct heads, referring to the works already alluded to for further details.

Another part of the same subject, however, remains to be fairly appreciated ; namely, the chemical changes that take place during, and subsequent to the action of mere mechanical force ; and though perhaps at present this subject is not fully ripe for discussion, it cannot be other than useful to suggest, both to the chemist and geologist, many facts really unexplained by either of them. In the present chapter we shall merely give an account of the mechanical effect of the changes already spoken of as occurring in the condition and position of the air and water.

* Geschichte der durch überlieferung nachgewiesenen natürlichen veränderungen der Erdoberfläche. Gotha, 1824—1834. "History of Natural Changes of the Earth's surface as proved by actual observation."

133. The following scheme will show the nature of the changes that take place at the earth's surface, and the order in which the various facts are described in the present chapter :—

I. Destructive Influence.

A. Atmospheric and meteoric action.
- *a.* By disintegration, § 134.
- *b.* By mechanical force, § 135.
- *c.* By electric discharges, § 136.

B. Aqueous action.
- *a.* By chemical agency, § 138.
- *b.* By mechanical force directly.
  - *α.* Of running water, § 139, 140.
  - *β.* Of falling water, § 141.
  - *γ.* Of sudden torrents of water, § 142—144.
  - *δ.* Of torrents of mud, § 145.
  - *ε.* Of sea-waves, § 147—151.
- *c.* By mechanical force indirectly.
  - *α.* By undermining § 152, 153.

C. Glacial action.
- *a.* Destroying rocks by frost, § 154—156, 161.
- *b.* Transporting rocks by glaciers and icebergs.
  - *α.* into valleys, § 157.
  - *β.* across seas, § 158—160.

II.—Reproductive or Conservative Influence.

A. By matter held in suspension in water.
- *a.* Deposited in river courses, § 163, 164.
- *b.* Deposited in lakes, § 165.
- *c.* Deposited along lines of coast, § 166—172.

B. By matter held in solution in water.

III.—Order of Arrangement of Deposited and Transported Material.

A. Under atmospheric influence, § 174.
B. Under the action of running water, § 175.
C. In the sea, § 176.

IV.—Organic Influence.

A. In association with various materials, § 177.
B. As forming distinct rocks, § 178—181.

134. The destructive action of the atmosphere is not generally manifest, except in the disintegration of exposed rocks, into which from time to time a quantity of water penetrates, and in which, owing to conditions of climate, this water occasionally cools down rapidly, below the temperature of its extreme contraction. Such action is seen either in high mountainous districts, where peaks of naked rock are exposed daily to great alterations of temperature, or where certain very decomposable rocks are exposed at the surface. The subjoined diagram will give a good idea of the grotesque forms thus assumed by granite in the latter case, but it is important to observe, that both in this rock, and in many limestones, sandstones, and slates, the degradation extends for a considerable depth below the surface, a result that may be due to the penetration of water containing acids. Occasionally, indeed, a decomposed rock has been subsequently recon-

solidated by the infiltration of water holding carbonate of lime or iron, and sometimes there are presented curious and regular forms, into which the surface has been hollowed.

Fig. 4.

Degradation of Granite by Atmospheric Exposure.

135. The winds occasionally modify the surface, especially in pushing forward hills of loose sand on exposed coasts, and in deserts. In these cases there is usually a slope and a steep side to the hill, as seen in the annexed diagram, (fig. 5,) where the wind is sup-

Fig. 5.

Advance of Sand dunes.

posed to have blown from *a* towards *b*, first pushing the sand up the slant side of the hill, and then pushing it over from *b* to *c*, after which it is again pushed up in a similar way to the summit of a next hill, and so on. Where this kind of motion is pretty constant the total advance per annum has been known to amount to from 60 to 70 feet, and many parts of the coasts of England, Holland, Flanders, France, and Portugal, present remarkable instances of villages that are almost or entirely submerged by such advance and encroachment of sand.

Indurated dunes exist in New Holland, at Guadaloupe, in Madeira, and other places, where water charged with carbonate of lime, iron, or perhaps silica, has hardened the loose sand ; and sometimes the roots of a plant (most commonly the *Arundo arenaria*) bind together the sand into a firm mass, which is then no longer drifted.

There is proof of the advance of dunes on the coast of Spain, oft Cape Finisterre, to the extent of about 16 miles in half a century, showing an average rate of upwards of 560 yards per annum ; but this is an extreme case.

136. Occasionally rocks have been altered by electric discharges, either cementing sand by absolute fusion, in consequence of the presence of potash, or splitting off and removing large solid fragments. Loose sand is the chief rock acted on in the first

mentioned manner, and the results have been not a little curious. The depth to which the fusion from the electric spark has extended, is in some places more than 30 feet, and the thickness of the vitrified walls of the tube produced, as much as $\frac{1}{10}$th of an inch. These tubes, thus formed of fused sand or glass, and called *fulgurites*, are generally compressed, furrowed in the direction of their length, and about 2 or 3 inches in circumference. They are often forked, and several have been observed within a small area.

"At Funzie, in Fetlar, about the middle of the last century, a rock of mica-schist, 105 feet long, 10 feet broad, and in some places 4 feet thick, was in an instant torn by a flash of lightning from its bed, and broken into three large, and several smaller fragments. One of these, 26 feet long, 10 feet broad, and 4 feet thick, was simply turned over. The second, which was 28 feet long, 17 feet broad, and 5 feet in thickness, was hurled across a high point, to the distance of 50 yards. Another broken mass, about 40 feet long, was thrown still farther, but in the same direction quite into the sea. There were also many smaller fragments scattered up and down." *

137. We have now to consider the action of water on rocks, and this may take place either chemically, by actual solution or decomposition; or by loosening their cohesive force and allowing them to disintegrate; or lastly, and chiefly, by acting mechanically upon them, removing portions to a distance, rubbing and rolling them one against another. The solution and disintegration are easily understood, but the mechanical action is more complicated, and may take place either by the mere weight of water; by friction, when water moves over an exposed surface, as in rivers; by the acquired momentum of waves of translation, as in tidal action or marine currents; by impact, or the falling of water from a height, as in waterfalls; or lastly, by undermining, as when a soft bed, which forms the support of overlying rocks, is eaten away by the water, and the overlying mass is brought down by the action of its own gravitation, its support being removed.

138. The solvent power of water is no doubt exercised in every case where that fluid penetrates rocks, whatever the circumstances may be, but it is greatly assisted by the presence of carbonic acid, ammonia, and other substances, which very soon become mixed with it. On all the soluble salts, on many earths, and especially on limestone, the effect is very manifest, and in the latter case is often seen in large caverns, first hollowed out, and then partially filled up, owing to the presence of water containing carbonic acid. Water, issuing from deep sources at a high temperature, acts much more readily and extensively than when pure and cold.

139. The action of running water is seen in streams of all kinds, whether with or without rapids and waterfalls, and in these cases we have generally not only the action of the water, but also that of sand and other materials, conveyed along by it; and thus the obstacles presented in the river course, and frequently the banks themselves of the stream, are worn and washed away with extraordinary rapidity.

* Rev. G. Low, quoted in Lyell's "Principles," seventh edition, p. 284.

River courses are also sometimes swept out and modified in their progress to the sea, long after they have left the high ground, and while traversing nearly level plains, this being effected by the union of several streams into one principal channel, and the contraction of a multitude of smaller and shallower feeders into one river, having a much smaller sectional area than the sum of those of the different streams, and therefore running with greater rapidity. The mechanical force of every river-current is constantly exerted in pushing forwards detrital and fragmentary matter that has been introduced from without, and at the same time a constant deposit is taking place in the river bed, which if left, will ultimately choke up the original channel, and force the river to acquire a new one.

140. Among examples of the eroding action of running water, Sir C. Lyell* mentions the recent excavations by the Simeto, one of the principal rivers of Sicily, whereby a passage has been opened through a lava current in the course of about two centuries, measuring from 50 to several hundred feet wide, and in some parts from 40 to 50 feet deep. It should be remarked, that this lava is in no part porous or scoriaceous, but consists of a compact homogeneous mass of hard blue rock. In soft rocks, as on the flanks of Vesuvius, where torrents descend the mountain side after heavy rain, instances are on record of a passage 25 feet wide having been cut in three days, and other similar instances are well known.

141. The effect of a fall of water, either directly or by undermining soft strata, is often traceable, but perhaps nowhere to greater advantage than in the great Falls of Niagara.

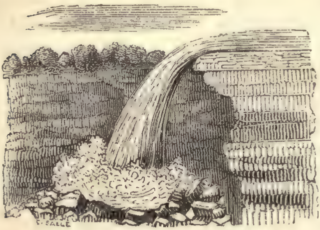
"It has long been the popular belief, that the river Niagara once flowed in a shallow valley across the whole platform, from the present site of the Falls to the escarpment (called the Queenstown heights) where it is supposed that the cataract was first situated, and that the river has been slowly eating its way backwards through the rocks for the distance of seven miles. This hypothesis naturally suggests itself to every observer, who sees the narrowness of the gorge at its termination, and throughout its whole course as far up as the Falls, above which point the river expands as before stated. The boundary cliffs of the ravine are usually perpendicular, and in many places undermined on one side by the impetuous stream. The uppermost rock of the table-land at the Falls consists of hard limestone, about 90 feet thick, beneath which lie soft shales of equal thickness, continually undermined by the action of the spray, which rises from the pool into which so large a body of water is projected, and is driven violently by gusts of wind against the base of the precipice. In consequence of this action, and that of frost, the shale disintegrates and crumbles away, and portions of the incumbent rock overhang 40 feet, and often when unsupported, tumble down, so that the Falls do not remain absolutely stationary at the same spot, even for half a century." †

A somewhat similar condition to that above described, is represented in fig. 6, which illustrates the mode in which falling water destroys and eats out hard rock, leaving a projecting ledge, which, however, is constantly being removed and as often replaced.

* Lyell's "Principles," *ante cit.*, p. 201. † Ib. p. 203.

142. The power of running water in removing stones is well seen when the usual rate of motion of river-currents is greatly accelerated in consequence of some temporary flood. Such an instance occurred in Scotland in 1829, where the whole length of rivers flooded could not have been less than 500 miles, and by which 38 bridges and a vast number of farms and hamlets were totally obliterated. A detailed account of these floods was published by Sir T. Dick Lauder, in 1830, and presents many remarkable examples of the force exerted by rapidly moving water, loaded with fragments which it had already torn from their original position. In a case recorded by Mr. Culley in the Proceedings of Geological Society (vol. i. p. 149), heavy rains falling during three days of August 1827 swelled to an unusual height the small rivulet called the College, which flows at a moderate declivity from the eastern watershed of the Cheviot Hills, and caused that stream not only to transport enormous accumulations of several thousand tons weight of gravel and sand to the plain of the Till, but also to carry away a bridge then in progress of building, some of the arch-stones of which, weighing from half to three quarters of a ton each, were propelled two miles down the rivulet.

Fig. 6.



Action of Falling Water on Hard Rock.

On the same occasion, the current tore away from the abutment of a mill-dam a large block of greenstone-porphyry, weighing nearly two tons, and transported the same to the distance of a quarter of a mile. Instances are related as occurring repeatedly, in which from 1000 to 3000 tons of gravel have been in like manner removed to great distances in one day, and the author asserts, that whenever 400 or 500 cart-loads of this gravel are taken away for the repair of roads, one moderate flood replaces the amount of loss with the same quantity of rounded debris.

143. Freshets, or periodical floods of small extent, occur in many rivers, and produce considerable results ; large quantities of detritus and deposits of larger kind than the mere river silt being carried forwards to a distance, and at length removed into the sea. It has been observed, that during freshets, a river tends chiefly to widen its bed, without greatly deepening it, for the aquatic plants, the silt and the gravel, are not swept away, but rather defend the bottom of the river, while on the contrary the banks are exposed, and as well as the lowlands on each side, are frequently washed away.

144. Torrents are often produced after floods and freshets, where the water is dammed up for a time, and then breaks through all

obstacles. Examples of a remarkable kind have often been quoted, and one of very great extent which occurred in 1818 in the Vallais (Switzerland), is a good instance of the vast rapidity with which causes of this kind act. In this case, a lake containing 800,000,000 cubic feet of water was formed in winter, the water being held back in a valley by rocks and masses of ice, thrown down chiefly by avalanches. The lower part of the embankment thus formed, was partly undermined, and a large quantity of water flowed through it, although not enough to drain the lake, and thus when the warm weather came the whole barrier gave way, and the waters were all discharged in half-an-hour. The torrent reached the Lake of Geneva (a distance of forty-five miles) in six hours and a half, and the destruction caused by it involved every house, tree, or other object in the way. Other instances have frequently occurred, by which whole villages have been entirely swept away, and as there are many instances in which bodies of water, many thousand times greater than the largest of these, are now above the general level of much surrounding land, debacles of the same kind, and of enormously greater extent, may be looked for at some future time, and may have happened in former ages.

The vast depression of the Aralo-Caspian sea may one day be filled up by a rush of water coming in from the Mediterranean, and the smaller but much deeper hollow of the Dead Sea may also hereafter be a scene of destruction from water, as we are told it was once by fire.

145. Besides these torrents of water, others occur from time to time, in which mud is poured out from some concealed lake beneath a turf bog, or from some volcanic vent. Examples have occurred of the first kind in Ireland, in the valley of the Arve, and elsewhere; and of the latter kind in Java and Peru. They are referred to in another paragraph (§ 187).

146. Currents of water necessarily produce results, the more disastrous as the slope of their course is greater, but it need not be supposed that this slope must be considerable to cause a mischievous torrent. The most rapid streams having a continuous bed not broken by rapids offer slopes of only 1° or 2°, and yet are capable of conveying along blocks nearly half a yard in diameter, and many rivers flow rapidly with infinitely smaller inclinations, navigable streams rarely having a slope of more than 3′ to 4′, and the most rapid of the larger European rivers, the Rhine and Rhone, presenting a mean of from 1′ to 2′, while in some parts they only run on a slope of 4″ to 8″. These data are important for comparison, for we may thus see the prodigious result that would be produced on more considerable slopes, or even by a greater depth of water, since in the latter case the friction on the sides and banks would be diminished.*

147. We come next to the action of the sea, which is partly undermining, but chiefly consists of the direct effect of waves beating against exposed shores. The action of the tide-wave is alternating, for it both advances and recedes, destroying as it advances, and carrying away the debris as it recedes. The waves of currents act only in one direction, continually beating against an obstacle

* See Beudant's "Geologie," p. 70.

and removing the fragments frequently to a considerable distance in the direction of their course, and thus when tidal action and that of marine currents are combined they are likely to produce marked results, the joint action being very great. Currents are frequently produced by tidal action in confined seas, and seas where there are many islands, especially if the depth of water is great.

148. It is not easy to estimate the true extent of the action of the tide-wave beneath the surface, but its effect between high and low water has been frequently noticed and recorded. Sir H. de la Beche in his "Manual," has mentioned several instances on the British shores, where the tidal wave would seem not to disturb shoals at even moderate depths,* but on the other hand, M. Siau has observed tidal action in the bay of St. Paul's (Isle of Bourbon) at a depth of 622 feet, on a bed of sand and basaltic gravel.† It is not unlikely that the greatest effect is produced where the tide-wave has been least interfered with by the form of the land.

Fresh water moving with a velocity equivalent to $1\frac{1}{2}$ mile per day, is said to be sufficient to tear up fine clay; a velocity about six times as great, or about $8\frac{1}{2}$ miles per day removes fine sand; 17 miles per day removes fine gravel; and 50 miles per day, or little more than 2 miles per hour, carries along angular stones of ordinary kind nearly as large as an egg. These of course are the rates of motion which the water must have at the bottom of a stream, where the friction is considerable. The rate of a stream's motion at the surface is very much greater than at the bottom, but this is not the case when water is moved along in a wave of translation, the velocity being then greater in deep water than at the surface.

Fig. 8. Fig. 7.

Action of the Waves on Steep Cliffs.

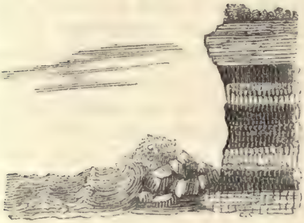
149. The effect of aqueous action is well seen on many parts of the Atlantic coast of Europe and America, but varies greatly in extent according to the nature of the exposed shore. Thus, when the waves come in upon a flat and gradually shelving coast without impediments, the effect is rather to contribute new deposits than to remove those which already exist. When there is an exposed cliff, the rocks being horizontal, but the lower ones not much harder than the upper (fig. 7), the cliff is undermined, and the debris are carried away every tide, so that the work of destruction goes on very rapidly. This is the case remarkably on the east coast of England, where many villages have disappeared, and broad tracts of the coast removed, even where the cliffs are not less than 300 feet in height.

* Geological Manual, third edition, 1833, p. 110.
† An. de Physique for 1841, second series, vol. ii. p. 118.

Under circumstances apparently less favourable, and where the rocks incline inland, as represented in the other part of the same diagram (fig. 8), the same thing must necessarily happen, for the upper rocks losing their support will after a time fall into the sea, even if not assisted, as is generally the case, by the action of the atmosphere and frost during winter.

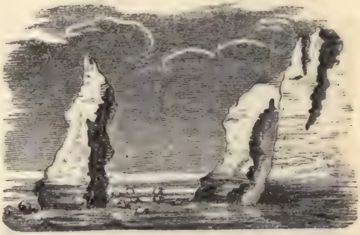
150. It occasionally happens, however, as in the case represented in fig. 9, that the debris produced at first by the action of the waves accumulate at the base of a cliff, and form a natural rampart preventing farther destruction. It is this condition that is frequently imitated by engineers when they desire to prevent further encroachments of the sea on an exposed coast.*

Fig. 9.



Natural Breakwater formed by Falling Rocks.

Fig. 10.



Chalk Needles on the Coast of France.

151. The effect of this constant abrasion on exposed coasts is seen also in the eating out of caverns, the formation of natural bridges by the removal of the lower parts of projecting headlands, and the actual separation of promontories from the main land, thus forming islands and isolated needles and pinnacles. Such a case is exemplified in fig. 10, where peculiar forms are represented, into which the chalk of the Normandy coast, a particularly soft rock, has been worn ; and other cases are well known, as for instance the "Needles," also of chalk, at the western extremity of the Isle of Wight, and those at Flamborough Head. Elsewhere much harder and tougher rocks have been acted on as shown in fig. 11, where very striking and picturesque appearances are represented. The following account of these by Dr. Hibbert, from his description of the Shetland Islands, will be found interesting and instructive.

"The most sublime scene is where a mural pile of porphyry, escaping the process of disintegration that is devastating the coast, appears

* Examples of the destructive force of the waves are given in great detail in Lyell's "Principles," already more than once quoted; and the general nature of such action is enlarged on in the work published by Sir H. T. de la Beche under the title "How to Observe—Geology." Much useful information is contained in this latter work, and to it we are indebted not only for the enunciation of many principles, but for the illustrations above given, which were copied by M. Beudant, and have been from his work transferred to the present one.

to have been left as a sort of rampart against the inroads of the ocean; the Atlantic, when provoked by wintry gales, batters against it with all the force of real artillery, the waves having, in their repeated assaults, forced for themselves an entrance. This breach, named the Grind of the Navir (fig. 11), is widened every winter by the overwhelming surge, that finding a passage through it separates large stones from its sides, and forces them to a distance of no less than 180 feet. In two or three spots the fragments which have been detached are brought together in immense heaps, that appear as an accumulation of cubical masses, the product of some quarry."*

Fig. 11.

Grind of the Navir. Passage forced by the Sea through Rocks of hard Porphyry.

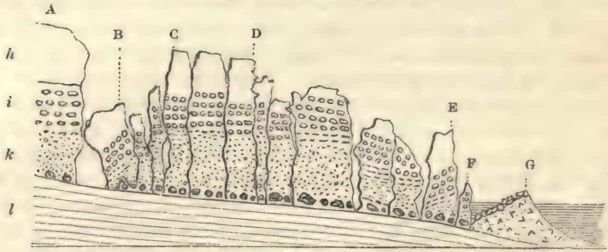
In estuaries the combined influence of tides, and the currents derived from and connected with them, is sometimes very considerable, and is, of course, chiefly exerted in modifying the coast line.

152. Landslips afford other examples of the action of water, and an extraordinary instance occurred on the 24th of December, 1839, on the coast between Lyme Regis and Axmouth, which has been described by the Rev. W. D. Conybeare, and to which the annexed diagram refers. "The tract of downs ranging there along the coast is capped by chalk (*h*) which rests on sandstone, alternating with chert (*i*), beneath which is more than 100 feet of loose sand (*k*), with concretions at the bottom, and belonging, like *i*, to the green sand formation; the whole of the above masses, *h*, *i*, *k*, reposing on retentive beds of clay (*l*) belonging to the lias, which shelves towards the sea. Numerous springs issuing from the loose sand (*k*) have gradually removed portions of it, and thus undermined the superstratum so as to have caused subsidences at former times, and to have produced a line of undercliff between D and E. In 1839 an excessively wet season had saturated all the rocks with moisture so as to increase the weight of the incumbent mass, from which the support had already been withdrawn by the action of springs. Thus the superstrata were precipitated into hollows prepared for them, and the adjacent masses of partially undermined rock, to which the movement was communicated, were made to slide down on a slippery basis of watery sand towards the sea. These causes gave rise to a convulsion, which began on the morning of the 24th of December,

* Dr. Hibbert, p. 528, quoted in Lyell's "Principles."

with a crashing noise; and on the evening of the same day fissures were seen opening in the ground, and the walls of tenements rend-

Fig. 12.
Landslip near Axmouth, Dec. 1839.



A Tract of downs at their original level.
B New ravine.
C, D Sunk and fractured strip united to A before the convulsion.
D, E Bendon undercliff as before, but more fissured, and thrust forward about 50 feet towards the sea.
F Pyramidal crag sunk from 70 to 20 feet.
G New reef upheaved from the sea.

ing and sinking, until a deep chasm or ravine, B, was formed, extending nearly three-quarters of a mile in length, with a depth of from 100 to 150 feet, and a breadth exceeding 240 feet. At the bottom of this deep gulf lie fragments of the original surface thrown together in the wildest confusion. In consequence of lateral movements the tract intervening between the new fissure and the sea, including the ancient undercliff, was fractured, and the whole line of sea cliff carried bodily forwards for many yards. A remarkable pyramidal crag, F, off Culverhole Point, which lately formed a distinguishing landmark, has sunk from a height of about 70 to 20 feet; and the main cliff, E, before more than 50 feet distant from this insulated crag, is now brought almost close to it. This motion of the sea-cliff has produced a further effect, which may rank among the most striking phenomena of this catastrophe. The lateral pressure of the descending rocks has urged the neighbouring strata, extending beneath the shingle of the shore, by their state of unnatural condensation, to burst upwards in a line parallel to the coast; thus an elevated ridge, G, more than a mile in length, and rising more than 40 feet, covered by a confused assemblage of broken strata and immense blocks of rock, invested with sea-weed and corallines, and scattered over with shells and star-fish, and other productions of the deep, forms an extended reef in front of the present range of cliffs." *

* Dr. Conybeare, as quoted in Lyell's "Principles," 7th edit. p. 307.

153. Another example of the undermining action of water was afforded by the remarkable fall of the Rossberg, in Switzerland, which took place in 1806, after a very rainy season. In this case much clayey matter, which served as a cementing medium of the pebbles and boulders of which the mountain is formed, was washed away, and a mass measuring nearly two thousand millions of cubic feet was precipitated into the valley, forming hills nearly 200 feet high, and burying several villages. Landslips have occurred of late years in England of the same nature, though not to so great an extent.

154. In addition to the direct action of water in disturbing the existing condition of the earth's surface, there is another and no less influential way in which it acts, in climates or at elevations where the temperature frequently descends below the freezing point of water.* In mountain districts where there are sheltered valleys, large masses of ice often accumulate and descend far below the level of perpetual snow, conveying with them vast quantities of detritus either to the valley into which they open, or if near the coast, quite into the sea. In the former case their transporting power is soon brought to a close, but in the latter they may then commence journeys of many hundred, or even thousand miles, conveyed along by the marine currents which set from the cold seas into those of more temperate climates.

The phenomena of *glaciers* and *icebergs*—as the masses of ice are designated in these two cases respectively—are exceedingly striking and very influential in modifying the general surface of the land in temperate climates; and this subject having important bearing on many geological inquiries deserves serious attention.

155. Glaciers have been chiefly studied in the Alps, where a number of beautiful and instructive examples are known, and where the climate is sufficiently moderate to allow of their careful and detailed examination with comparative convenience. "The common form of a glacier," says Professor J. Forbes, speaking of these Swiss examples in his admirable "Travels through the Alps of Savoy," "is a river of ice filling a valley, and pouring down its mass into other valleys yet lower. It is not a frozen ocean, but a frozen torrent. Its origin or fountain is in the ramifications of the higher valleys and gorges, which descend amongst the mountains perpetually snow-clad. But what gives to a glacier its most peculiar and characteristic feature is, that it does not belong exclusively or necessarily to the snowy region already mentioned. The snow disappears from its surface in summer as regularly as from that of the rocks which sustain its mass. It is the prolongation or outlet of the winter-world above; its gelid mass is protruded into the midst of warm and pine-clad slopes and green-sward, and sometimes reaches

* See § 27.

even to the borders of cultivation. The very huts of the peasantry are sometimes invaded by this moving ice, and many persons now living have seen the full ears of corn touching the glacier, or gathered ripe cherries from the tree with one foot standing on the ice." *

156. Glaciers become more and more numerous in mountain districts as we advance from the temperate zones towards the poles, and at the same time they reach gradually nearer the sea level, till at length they project into the sea. At first these portions enter a sea warmer than the freezing point of water, and are either entirely melted, or broken off and floated away in small masses. At length, however, as the quantity of ice near the coast and the rapidity of its motion onwards gradually increases, and the sea also becomes colder, the extent and thickness of the glaciers increase in a corresponding degree, until they almost cover the land near the coast. In still higher latitudes we arrive at regions where the ice projects so far into the ocean, and to such enormous depths, that, in spite of the load of rocks and earth also conveyed, the quantity of ice beneath the surface is sufficiently large (ice being specifically lighter than even fresh water, and, therefore, much lighter than that of the sea), to overcome the cohesion of the mass, and it then breaks and floats off as an island. There are thus in cold seas two kinds of ice—ice-fields or floes, which are large, flat, and shallow sheets of ice, the result of the freezing of the surface of the water during intense cold, and the deeper, larger, and greatly loaded masses or islands called icebergs.

157. The surface and substance of glaciers and icebergs always abound with fragments of rock, which are of various sizes, from that of a house to the finest mud and sand, and when they appear in long lines in the direction of motion, are called *moraines*. The rocks over which the glacier passes, whether on the mountain side or elsewhere, are usually rounded, smoothed, scratched, and indented; as if by the edges of blocks of hard angular stone or finer sand, forcibly dragged along under enormous pressure.

158. Glaciers generally terminate by a nearly vertical wall, marking the thickness of the tongue of ice at its extremity. In Switzerland this is rarely more than from 60 to 100 feet in height, but in arctic climates many instances have been seen where the thickness amounts to 350 feet, and some are recorded where a perpendicular cliff of ice rises above the water-line of a floating mass to the height of 150 feet, and therefore whose total height must have been more than 1000 feet. The magnitude of the section at the water line is also sometimes very considerable in the case of these floating masses of ice. They are very frequently from six to twelve hundred feet in length, and of about half that breadth, but some have been seen measuring between five and six miles in one direction.

* Forbes's Travels, p. 19.

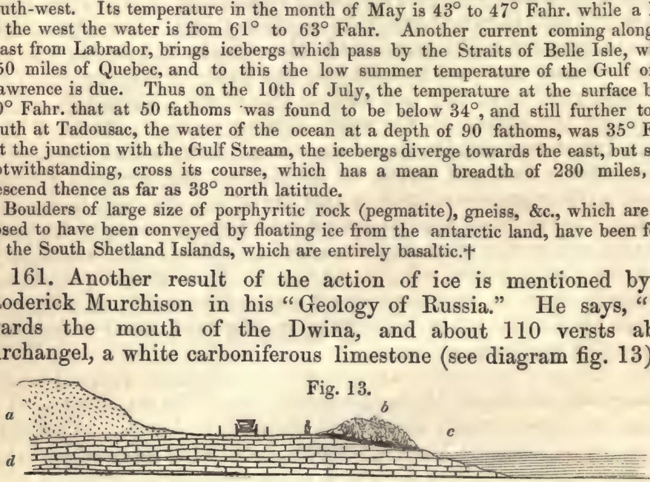
159. "Scoresby counted 500 of these bergs drifting along in latitudes 69° and 70° north, which rose above the surface, from the height of 100 to 200 feet, and measured from a few yards to a mile in circumference. Many of them were loaded with beds of earth and rock of such thickness, that the weight was conjectured to be from 50,000 to 100,000 tons. Specimens of the rocks were obtained, and among them were granite, gneiss, mica-schist, clay-slate, granular felspar, and greenstone. Such bergs must be of great magnitude; because the mass of ice below the level of the water, is about eight times greater than that above. Wherever they are dissolved, it is evident that the "moraine," will fall to the bottom of the sea. In this manner may submarine valleys, mountains, and platforms, become strewed over with gravel, sand, mud, and scattered blocks of foreign rock, of a nature perfectly dissimilar from all in the vicinity, and which may have been transported across unfathomable abysses. If the bergs happen to melt in still water, so that the earthy and stony materials may fall tranquilly to the bottom, the deposit will probably be unstratified, like the terminal moraine of a glacier; but whenever the materials are under the influence of a current of water as they fall, they will be sorted and arranged according to their relative weight and size, and will therefore be more or less perfectly stratified." *

160. The icebergs appear to be conveyed from the cold shores of the Arctic Ocean by a current, which, proceeding along the shores of Greenland, approaches the Gulf Stream on the eastern side of the great Bank of Newfoundland, near latitude 44° north, and between longitude 45° and 48° west. The direction of this current is south-west. Its temperature in the month of May is 43° to 47° Fahr. while a little to the west the water is from 61° to 63° Fahr. Another current coming along the coast from Labrador, brings icebergs which pass by the Straits of Belle Isle, within 350 miles of Quebec, and to this the low summer temperature of the Gulf of St. Lawrence is due. Thus on the 10th of July, the temperature at the surface being 50° Fahr. that at 50 fathoms was found to be below 34°, and still further to the south at Tadousac, the water of the ocean at a depth of 90 fathoms, was 35° Fahr. At the junction with the Gulf Stream, the icebergs diverge towards the east, but some, notwithstanding, cross its course, which has a mean breadth of 280 miles, and descend thence as far as 38° north latitude.

Boulders of large size of porphyritic rock (pegmatite), gneiss, &c., which are supposed to have been conveyed by floating ice from the antarctic land, have been found in the South Shetland Islands, which are entirely basaltic.†

161. Another result of the action of ice is mentioned by Sir Roderick Murchison in his "Geology of Russia." He says, "Towards the mouth of the Dwina, and about 110 versts above Archangel, a white carboniferous limestone (see diagram fig. 13) oc-

Fig. 13.



Ridges of Blocks on the Dwina.

cupies the bank in horizontal layers, the edges of which are partially covered with mud and sand. The limestone is best seen when the water is low, as at the period of our visit. About thirty feet above the summer level of the stream, the terrace on the river-side is covered for two or three versts by a band of irregularly piled, loose

* Lyell's "Principles," *ante cit.* p. 228.
† "Voyage of the *Bonite*," Geologie et Mineralogie.

and large angular blocks of the same limestone, arranged in a long, uniform ledge, the surface of which slopes both to the river and to the roadway, so that the view of the stream is shut out from the traveller by this ledge. In other words, these materials (all purely local) constitute a broken ridge of stones between the road and high-water mark. A woodcut will best explain these appearances (see fig. 13), showing (*a*) the ancient hillocks of sand above the road-terrace, which is partially covered with water at high inundations, (*b*) the ridge of broken limestone, (*c*) the sloping river-bank. The occurrence of these supra-riparial ridges of angular blocks *in situ* is thus explained:—When the Dwina is at its maximum height, the water which then covers the edges of the thin beds of horizontal limestone (*d*) penetrates into its chinks, and, when frozen and expanded, causes considerable disruptions of the rock, and the consequent entanglement of stony fragments in the ice. In the spring the fresh-swollen stream inundates its banks (here very shelving), and upon occasions of remarkable floods so expands that in bursting it throws up its icy fragments to fifteen or twenty feet above the highest level of the stream. The waters subsiding, these lateral ice-heaps melt away, and leave upon the bank the rifted and angular blocks (*b*), as evidences of the highest ice-mark. In Lapland Mr. Böhtlingk has adduced some extraordinary examples of this sort of glacio-fluviatile action; for he assures us that he there found large granitic boulders, weighing several tons, actually entangled and suspended like birds' nests in the branches of pine-trees at heights of thirty or forty feet above the summer level of the streams." *

162. Among the results of that kind of atmospheric and aqueous action described in the preceding paragraphs of this chapter we may mention, 1st. the rough and broken surface observable in countries where naked rocks appear at the surface;—2nd. the soil derived from the pounding up of the broken fragments in other districts; —3rd. the bold and scarped appearance, and the low, muddy, or shingly tracts observable on the coast;—4th. the gradual silting up of river beds and lakes; — in the former case altering the original course of the stream, and forming a new one, and in the latter entirely obliterating the lakes;—5th. the accumulation of detritus at the mouths of large rivers, and the formation of oceanic and river deltas; — and, 6th. the distribution of large quantities of mud, stones, sand, and other transported material on the sea-bottom, either near or at a distance from the land. It remains to consider, briefly, the extent to which such action has been traced in cases not yet alluded to, and to observe the laws according to which the matter deposited seems to be arranged.

Enough has been already said in previous paragraphs concerning

* "Geology of Russia in Europe and the Ural Mountains," vol. i. p. 506.

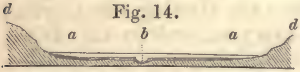
the first, second, and third of the results mentioned above, which are chiefly or entirely destructive, and what now remains has reference chiefly to the silting up of rivers and lakes, and the formation of deltas — these being the *reproductive* effects of aqueous action—and to the arrangement and distribution of materials thus accumulated.

163. We have first to take into account the actual amount of reproductive effect produced by running water in some particular cases of streams and lakes; and here, as before, we cannot do better than give one or two statements carefully compiled from the best authorities, and refer to books already quoted for further and more detailed illustrations.

An admirable example of the deposit of mud as new land is seen at the head of the Adriatic Sea, where no tides or strong currents interfere with the gradual accumulation of river mud, and which receives two considerable rivers, the Po and the Adige, draining a wide range on the south side of the Alps and passing through the great plains of Lombardy. "From the northernmost point of the Gulf of Trieste to the south of Ravenna there is an uninterrupted series of recent accessions of land, more than 100 miles in length, which within the last twenty centuries have increased from two to twenty miles in breadth." "It is calculated that the mean rate of advance of the delta of the Po on the Adriatic, between the years 1200 and 1600 was nearly eighty feet a-year, and the mean annual gain from 1600 to 1804 was upwards of 220 feet;" and we may mention, as other results, that Adria, a sea-port in the time of Augustus, that gave its name to the adjacent gulf (Adriatic), is now upwards of twenty miles inland.

164. Rivers exhibit the accumulations of mud due to their passage over a country, partly by this increase of land along a coast line, but partly also in the elevation of their actual bed and of the adjacent valley, and the filling up of the lakes through which they pass. The result rapidly increases as the work goes on, as will be understood by referring to the annexed diagrams, where fig. 14 represents a section across a river course at the commencement of the deposit, the river (b) then running through the lowest part of a valley (a a), between high lands (d d). When the stream is flooded the mud will be partly deposited over the whole section, but a large proportion of the turbid water will flow off, draining back as the stream recovers its natural level. When, however, the stream has in the course of time raised its bed by successive deposits (see fig. 15), and the floods cover the adjacent country, the water will be kept back in the hollows at a a, till evaporated, and the

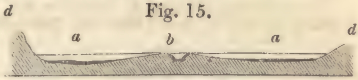
Fig. 14.



Mud deposited by floods when a stream runs on a low bed through a valley.

whole of the mud must be left behind. Thus the valley is gradually elevated so long as the same causes continue to operate. In the case of larger rivers, as the Ganges, the Mississippi, and others, the thickness of the alluvial bed near the river mouth becomes very considerable, and even at a distance of a hundred miles or more up the stream, and in the open plains through which the river makes its way, is estimated in the Mississippi at more than 250 feet. All this has, of course, been accumulated by the reproductive action of the river itself.

Fig. 15.



Mud deposited by floods when a river has raised its bed.

165. When a triangular area of land is added to the previously existing shore, whether of the sea or a lake, the base of the triangle extending towards the open water and the apex being up the stream, it is called a *delta,* from the form of the Greek letter of that name. Such deltas accumulate often rapidly, and mountain lakes are not unfrequently entirely filled up by them in the course of time. In the Lake of Geneva the Rhone enters as a turbid stream, charged with a large quantity of mud and detritus, but goes out at Geneva perfectly transparent. The whole of the mud is left near the head of the lake, which has thus become very shallow, and the new matter now annually added, is thrown down upon a slope about two miles in length. The higher part of the Lake of Como is nearly filled up, and the lake divided into two, by the detritus transported by the Adda and Mera; the Lago Maggiore by the Ticino; and many others in like manner. Some large inland seas, as the Baltic, are sensibly reduced in depth by the accumulations of mud that take place in them, and the Mediterranean is gradually encroached on by many of the rivers that empty themselves into it. Of these the Nile and the Rhone are the most important, but large results are produced by the infinite multitude of small streams entering along its coast line.

166. The Delta of the Nile now commences about 100 miles in a direct line from the Mediterranean, and is at least 230 miles in breadth; but the chief effect of the mud brought down by this river, and deposited near its mouth, is not so much seen in the extension of the delta seawards as by the elevation of the land over which the periodic floods of the Nile extend, and which is therefore gradually increasing in extent. The mud of the river consists of nearly one moiety of argillaceous earth, together with variable proportions of carbonate of lime, carbon, silica, magnesia, oxide of iron, and carbonate of magnesia. Each year produces a thin additional layer, not thicker, on an average, than a sheet of thin pasteboard. The whole area of the delta, with the exception of a few sand-hills

and artificial tumuli, offers a perfectly level plain, intersected in every direction by channels. The slope or fall of the Nile from Cairo is about one in sixteen thousand, equivalent to 15″.

The following analysis of the dried mud of the Nile has been recently made by M. Lassaigne, and is quoted from the Quarterly Geological Journal, vol. v. part ii. p. 20.

Silica	42·50
Alumina	24·25
Magnesia	1·05
Peroxide of iron	13·65
Carbonate of lime	3·85
Carbonate of magnesia	1·20
Humic acid	2·80
Water	10·70
	100·00

167. The delta of the Rhone forms a range of marshes bordering the Mediterranean between Marseilles and Cette, and includes about 320,000 acres. A large part of it is called the Camargue, and includes about 180,000 English acres, of which a considerable portion is covered to a small depth by water. The ancient and original mouth of the Rhone was on the western side of this area, and the actual embouchure has advanced more than eight miles towards the sea since the commencement of the Christian era. Several towers and other buildings mark distinctly the progress thus made.

168. The Danube, another principal river of Europe, emptying itself into a nearly closed sea, presents a large delta, the river dividing into four principal branches at about fifty miles from the coast, the two extremes of which are about fifty-four miles apart at the extremity. The Volga affords a similar instance of the accumulation of mud, as there are only a few feet of water in the Caspian Sea for a distance of fifty miles from the mouth of that river.

169. The Oceanic deltas, of which in Europe the Rhine is the most extensive, offer examples of the reproductive effect of river currents on a very large scale. The present head of the delta is about forty-five miles from the nearest part of the Zuyder Zee, and more than ninety miles from the general coast line. The whole of the coast line of Europe, however, from Calais to the entrance of the Baltic, requires to be considered in reference to this considerable and important delta; and, as the subject has been ably treated, and at some length, by M. Elie de Beaumont,* we must refer to his account for the details, without which it is not easy clearly to understand the nature and cause of the coast changes constantly going on. It appears that the whole plains of North Central Europe have been originally covered by sand and gravel, but chiefly by the fine sand seen on the coast of Flanders. On these have been

* "Leçons de Geologie pratique," vol. i. p. 253, *et seq.*

deposited the accumulations of mud brought down by the Rhine, and the numerous sinkings for wells in various parts of Holland and Belgium show that such accumulations amount in places to several hundred feet.

170. The waters of the Rhine, as of other rivers, have been examined with reference to the average quantity of solid matter they hold in suspension at different periods of the year, and it was found, by two sets of experiments made by Mr. Leonard Horner at Bonn, that the quantity brought down was about 400 tons weight per hour.

171. The Ganges, including the Bramahpootra, presents a delta of gigantic dimensions, and is well worthy of notice. It commences 220 miles from the sea, and its base line extends for 200 miles, including the wide tract occupied by the waters of the river and the different branches, of which there are eight principal and an almost infinite number of smaller ones. These are constantly shifting, and the extremity of the delta altering in position; and the quantity of mud poured into the Bay of Bengal is so large that the sea does not recover its transparency for sixty miles from the coast. The general slope seawards is gradual, and, with the exception of a deep hollow about fifteen miles in diameter, is not more than sixty fathoms deep at a distance of a hundred miles out. The quantity of mud brought down by this river has been estimated at about 500,000 cubic feet per second during the four months of the flood season, and about 50,000 cubic feet only per second for the rest of the year; the average weight of mud during the rains being $\frac{1}{428}$th part of the whole weight of the water. The total annual discharge would thus be nearly 6,368,000,000 tons, and the average quantity of mud held in the water about $\frac{1}{450}$th part by weight.

172. The Mississippi commences to bifurcate at nearly 300 miles from its principal embouchure, and the head of its delta is about 200 miles from the sea. Its breadth is considerable, and it presents on the whole an area at least one third larger than that of the Nile. It is essentially a projecting delta, being bounded on the east, west, and south by the sea, and advancing steadily outwards, at a rate of about one mile in a century, or fifty feet per annum. The solid matter contained in the muddy waters of the river is nearly ten times as great as in the Rhine, averaging for the year $\frac{1}{1700}$th of the whole weight of the water. The mean depth of the mud and sand in the delta is estimated at not less than 500 feet, which, allowing 3,000,000 cubic feet of mud to be deposited each year, would require about 85,000 years for the formation of the present area of mud.* It is, however, probable, that the rate of increase has not

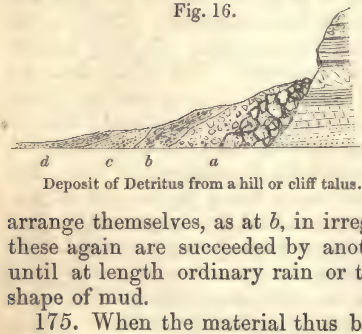
* "Lyell's Principles," *ante cit.* p. 218. The figures are somewhat altered to include recent observations.

always been the same, so that the present result may have been obtained in a much shorter time.

173. In addition to the material thus conveyed along by water a considerable quantity is deposited from calcareous and other springs. Several remarkable examples of this kind are quoted by Sir Charles Lyell, in one of which there is a thickness of 200 or 300 feet of travertin of recent deposit, while in another a solid mass 30 feet thick was deposited in about twenty years. He also states "there are countless other places in Italy where the constant formation of limestone may be seen," while the same may be said of Auvergne and other volcanic districts. In the Azores, Iceland, and elsewhere, silica is deposited often to a considerable extent. Deposits of asphalt and other bituminous products occur in other places.

174. We now come to the mode of distribution of the material removed, deposited, or otherwise accumulated in the manner above described. In the case of a cliff or hill the annexed diagram (fig. 16), will give some idea of the kind of process that takes place by the joint action of the atmosphere and water. The degradation at first results in the formation of a talus of large blocks (*a*) thrown down and irregularly heaped. After this a further amount of similar action breaks up these blocks into smaller fragments, which arrange themselves, as at *b*, in irregular parallelism with the former; these again are succeeded by another series, *c*, and these by others, until at length ordinary rain or tidal action removes a part in the shape of mud.

Fig. 16.



Deposit of Detritus from a hill or cliff talus.

175. When the material thus broken up is exposed to the action of running water, a certain amount of sifting takes place, and the materials are deposited in nearly horizontal layers with some degree of regularity, the finer and coarser portions being grouped separately. While, however, the deposit on the whole is nearly horizontal, different layers will present an internal arrangement of parts having reference to the actual direction in which the deposit was made, as marked in the diagram (fig. 17), where the direction of the current is marked by an arrow, and the beds *a*, *b*, have been deposited by an opposite current

Fig. 17.

Structure observed in the accumulations made by running streams.

to that which produced the earliest beds marked *c*, *d*. The bed *d* marks a peculiar lenticular, or lens-shaped form, not unfrequently seen, and due to a temporary and local cause often connected with the presence of some organic body.

176. All deposits are not of the simple character thus indicated. The results of the infiltration of water containing carbonate of lime, silica, oxide of iron, and various soluble earthy salts, through such accumulations, does not fail to produce considerable change in the course of time, and alternations of mere mechanical deposits with substances once held in solution will modify the first appearance and itself induce further change. The mud also deposited from the waters of a river, or on a coast, will be of various degrees of coarseness in any particular spot according to the mechanical force exerted, and every change, however small, will be marked by a slight, but corresponding alteration in the bedding; thus, in a moderate thickness of deposit we shall find a number of distinct bands, as in fig. 18, one of clayey mud, another of calcareous mud, another of sand, another of pebbles, and so on. These will have an arrangement without much reference to their relative specific gravity, except in the case of each band of similar materials.

Fig. 18.

177. But another real and great cause of difference in the deposits made both by and in water, must be traced to the organic world. Animals and vegetables inhabiting the water, or brought there by accident, so often possess hard and indestructible parts that these are constantly retained and preserved in mud, and not unfrequently make up very important and thick masses with little or no admixture of foreign and inorganic substances. Thus, shells of all kinds, particularly those exceedingly gregarious species common either in fresh-water, or in the sea, will be amongst these deposits, and they will also contain fragments of plants, both land and aquatic. Certain plants, however, are more readily preserved in water than others; and these, of course, will be chiefly retained, while many animals of low organization, such as those which secrete carbonate of lime from sea-water and form for themselves stony habitations, become permanent and important portions of the new condition of things. Such animals can withstand the beating of the waves, and their houses endure permanently as stony walls flanking extensive lines of coast and numerous detached islands. The coral animal of tropical and other seas is thus so dispersed in innumerable banks, and often builds such massive walls, that it ranks amongst the most effective causes of change, and requires some detailed explanation in this place. The coral animals, which are chiefly occupied in the

formation of reefs, have numerous calcareous plates, and increase with very great rapidity. In the seas where they build are also many bivalve and univalve shells, which add greatly to the mass. The reef-building corals do not flourish at a greater depth than 120 feet; and though many species are found living much deeper they rarely form considerable accumulations.

178. The appearance of a coral island is described by voyagers as extremely picturesque. A ring of land (see fig. 19) a few

Fig. 19.

View of Whit-Sunday Island, an atoll in the Pacific. for atoll vid. p

hundred yards wide, and measuring from less than one mile to thirty miles in diameter, rises barely above high water-mark, but is covered by lofty cocoa-nut trees. Between these and the water is a beach of glittering white sand, the outer margin of which is encircled with a ring of snow-white breakers, beyond which again are the dark heaving waters of the open ocean. The inner beach encloses the calm, clear water of a shallow lagoon, resting for the most part on white sand, and seeming of the most vivid green colour when the sun is shining. "The ocean," says Mr. Darwin, "throwing its breakers on the outer shore appears an invincible enemy, yet we see it resisted, and even conquered by means which at first seem most weak and inefficient. No periods of repose are granted, and the long swell caused by the steady action of the trade wind never ceases. The breakers exceed in violence those of our temperate regions, and it is impossible to behold them without feeling a conviction that rocks of granite or quartz would ultimately yield, and be demolished by such irresistible forces. Yet these low irresistible coral islands stand, and are victorious, for here another power, as antagonist to the former, takes part in the contest. The organic forces separate the atoms of carbonate of lime one by one from the foaming breakers,

and unite them into a symmetrical structure; myriads of architects are at work, night and day, month after month; and we see their soft and gelatinous bodies through the agency of the vital laws conquering the great mechanical power of the waves of the ocean, which neither the art of man, nor the inanimate works of nature, could successfully resist." *

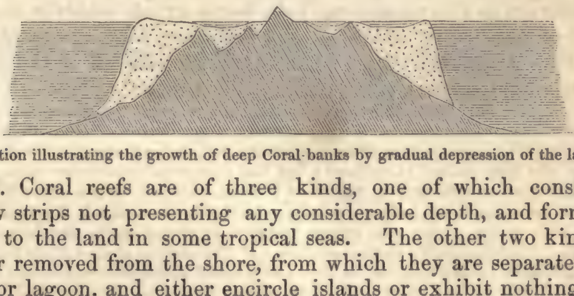
The structure of one of these islands will be understood by reference to the preceding sketch (fig. 19), and the accompanying section (fig. 20). In the diagram fig. 20, *a, a* represents the narrow habit-

Fig. 20.

Section across an atoll or lagoon island.

able ring; *b, b,* the lagoon, and *c,* an island rising out of the lagoon. Fig. 21, represents an ideal section of an island on which coral is supposed to have accumulated to a vast depth. See § 239.

Fig. 21.



Section illustrating the growth of deep Coral-banks by gradual depression of the land.

179. Coral reefs are of three kinds, one of which consists of narrow strips not presenting any considerable depth, and forming a fringe to the land in some tropical seas. The other two kinds are farther removed from the shore, from which they are separated by a canal or lagoon, and either encircle islands or exhibit nothing more than the narrow belt of the reef itself. The first kind are called *fringing*, the second *encircling* or *barrier*, and the third *atoll-formed* reefs, the name *atoll* being given, in the seas where these islands abound, to the circular reefs without high central land. Of these, fringing reefs occur in the Red Sea, on the east coast of Africa and Madagascar and the adjacent islands to the north, and in the Indian Archipelago between the Bay of Bengal and New Guinea and as far as the Solomon Islands, and they may be traced at intervals to the south of the Society Islands in longitude 150° W., and northwards through the Philippines. They also occur exclusively in the West Indies. The barrier reefs and atolls are found in the Indian Ocean, the China Sea, off the east coast of Australia, and in the Caroline Archipelago; and a vast multitude of islands as far as the Low

* "Journal of the Beagle," 2nd edit. p. 460.

Archipelago are built up in the same manner, the whole western portion of the Pacific being sometimes called the Coral Sea from the innumerable reefs and islands of coral that render navigation there so dangerous. The absolute area of sea bottom thus occupied at intervals by the work of one race of animals is so enormous that it would be difficult to parallel it by any reference to any existing mountain district,* and the actual magnitude of particular reefs is not less remarkable. Thus, the barrier reef in New Caledonia is 400 miles long; and on the coast of Australia the reef extends for 1000 miles parallel to the shore, and at a distance varying from 20 to 60 miles from it. The Maldive Archipelago is 470 miles in length, and has a mean breadth of 50 miles, and consists entirely of atoll islands, the largest of which is 88 miles in length, and only 20 broad. The Chagos group is a series of submerged atolls, and extends over an area of 170 miles by 80. The Laccadive group measures 150 miles by 100, and is of the same kind.

180. We are not at present concerned with the important theory of partial subsidence of large areas below the sea which the extent and condition of barrier reefs and atolls has suggested, but without any reference to this no one can help being struck with the vast and almost unmeasurable extent of the influence here exercised by a single race of organic beings on the great frame-work of the globe.

In a subsequent paragraph §239, some account is given of the reasons why a very considerable and long-continued depression of the land must be assumed to account for the great extent and thickness of the coral-reefs of the Pacific. It is hardly possible to exaggerate the importance of these phenomena within the present range of latitude to which the coral animal is confined; but this does not extend more than two or three degrees beyond the tropics, except in peculiar cases, where the water is warmer than usual, as in the West Indies. Coral is now chiefly abundant in the western part of the Pacific Ocean within the tropics, where most of the atolls and barrier reefs are found. Whether under former conditions of the earth's surface there may have been a difference in this respect, so that corals could attach themselves to shores in our latitude, is a subject which will be considered in a future chapter when treating of geological problems.

181. Nor are other and even much smaller animals without some means of producing results in mass. This has been remarkably shown in the case of infusorial animalcules inhabiting rivers where the tide periodically advances to a certain point and recedes, leaving a space alternately occupied by fresh water and salt. Many minute animals inhabiting the ocean and brought up by the tide are killed at once when immersed in fresh water.

The following is the result arrived at by Ehrenberg, with reference to this subject. It is taken from an abstract of a paper, originally published in the Proceedings of the Berlin Academy, 1843, and translated by the Author of the present work for the Quarterly Geological Journal, vol. i. (1845), p. 252.

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* From the southern end of the Low Archipelago to the northern end of Marshall Archipelago is a distance of 4500 miles, in which as far as is known *every* island, with one exception, is atoll-formed. The number of islands is so large that it has not yet been possible to estimate it correctly.

The minute microscopic animals of the sea extend up the bed of the Elbe, and this is probably the case also in all rivers directly connected with the ocean, as far as the ebb and flood of the tide are perceptible.

The flood-tide in the upper districts of the river, even where the salt taste is no longer perceptible, as above Hamburg, does not consist merely of an accumulation of the river waters, occasioned by checking its outflow, but is now proved to be due to the direct introduction of the sea water, probably under the river water, and extending very distinctly as far as 80 English miles above the mouth of the river.

Since in the lower portion of the Elbe, the mud, consisting of a mass of clay and slime, which often interferes with the navigation, only accumulates so far up as the flood tide is perceptible, but above this point the bed of the river consists of pure siliceous and other sand, it is evident that the cause of this singular phenomenon, which has hitherto not been sufficiently explained, is principally owing to organic conditions. It appears, in fact, that the mixture of river and sea water gradually kills vast multitudes of the minute organic bodies, and causes them to fall to the bottom, and form these accumulations.

The marsh land of the lower districts of the Elbe, below Hamburg, and, probably, of all rivers flowing into the ocean, although considered as humus, does not merely, or even chiefly, consist of matter brought down by the stream from distant regions, and still less is it a local production of the minute animalcules existing in river water, but it is to a very considerable extent derived from organic beings once existing in the ocean.

If we deduct the admixture of fine sand as a matter of uncertain origin, we shall find, not only at Cuxhaven, near the mouth of the Elbe, but also at Gluckstadt, that from one quarter to one third of the mass of fresh mud is owing to the influence of marine animalcules, and that above Hamburg, as far as the flood-tide extends, the proportion is about half as great, but it has been already shown that what appears to be fine sand, may also, in a great measure, be an altered state of organic siliceous shells.

Similar results were obtained from the examination of the mud in the lower districts of other rivers emptying themselves into the Baltic. In the neighbourhood of Hamburg, the thickness of this mud is 15 or 16 feet, and several low islands at the mouth of the Elbe are entirely formed in this way, the actual proportion of the skeletons of the animalcules being equal to one-twentieth of the volume. There is little doubt that this accumulation will be found to connect itself with the history of the earlier deposit of the great tract of land, whose northern shore is washed by the Baltic, and the eastern portion by the German Ocean.

182. Accumulations of vegetable matter must in like manner be forming important deposits which will one day appear as beds of coal or lignite, especially where swamps, turf-bogs, and other localities admit of the vegetable growth of each year being preserved. It seems to be chiefly in temperate and cold climates that these phenomena are most marked.

It is not necessary to detain the reader now with further details of the influence of organic products on inorganic matter, but that such influence is real and very extensive no one who is familiar with existing nature will for a moment doubt. Every accumulation of river mud and coast detritus must contain many fragments of the animals and vegetables, chiefly aquatic, existing in the vicinity; and as these are greatly influenced by climate, present local distribution of races, and past physical conditions on which this distribution depends, each spot where such accumulations go on, must present a history more or less complete of some part of the earth at one period

of its existence. The multitude of such chapters of the long and complicated history of the whole earth, that are in the course of time stereotyped in beds of mud, and will hereafter form rocks and be laid open to the naturalist and geologist, must, therefore, become records of the present condition of organic nature; and, however sometimes mixed and confused, will be true and trustworthy documents by which to study the history of the past. Similar documents discovered now in rocks and properly studied and interpreted are, and must be, the means of making out the true nature of the earth's progress; and these ancient records are generally available, whether they refer to animals or vegetables—to the highest or the lowest forms of organization.

183. As a fit conclusion to the present chapter we append an account of the views of Professor Edward Forbes concerning the distribution of marine animals in depth, since it is only by a knowledge of the actual laws of this distribution, and their bearing on the habits of animals generally, that any conclusions can be drawn from the appearance of the remains of various species embedded in aqueous deposits.

1st. Living beings are not distributed by chance in the bed of the sea; certain species inhabit certain localities according to depth, so that the bed of the sea presents a series of zones or regions, of which each one has its peculiar group of inhabitants.

2nd. The number of species is much less considerable in the deeper zones than those near the surface. Vegetables disappear below a certain depth, and the constant diminution in the number of species of animals indicates that the zero of animal life is not far distant.

3rd. The number of animal and vegetable species in the northern seas is not the same in all zones of depth: it increases in the number of identical or representative species as we descend. The law seems to be that the parallels in depth below the surface correspond in this respect to parallels of height above the surface, and have the same relation to parallels of latitude.

4th. All kinds of sea bottom are not equally capable of supplying nourishment for animals and vegetables.

5th. Banks of marine animals do not extend indefinitely, each species living in a particular sea bottom, and being liable to extinction if the number of individuals should increase so much as to modify the nature of the bottom.

6th. Animals inhabiting great depths have also a wide horizontal range.

7th. Mollusks emigrate in the larva state, but perish at a certain period of their existence, if they do not then find the conditions of depth and sea bottom favourable for their further development.*

* Ed. New Phil. Journ., April, 1845.

CHAPTER VI.

REACTION OF THE INTERIOR OF THE EARTH ON ITS EXTERNAL SURFACE.

184. The subject that comes now before us presents series of changes much more readily appreciated, and apparently more likely to modify the earth's surface, than those considered in the preceding chapter. It includes volcanoes and earthquakes, emanations of gas, and jets of hot and mineral water; and besides the great interest of the phenomena involved, the subject is of essential importance in enabling us to comprehend the general series of modifications of the surface of our globe. Following the plan adopted in the last chapter we commence with a scheme by which the reader will see at once the bearings of the subject, and the general mode in which it will be treated.*

I.—Direct indications of subterranean change.

A. By gaseous exhalations, and bituminous and muddy eruptions. § 185—188.
B. By thermal and mineral springs. § 189—194.
C. By undulations of the earth's surface propagated beneath the surface.
  a. Nature of earthquakes. § 195—198.
  b. Extent of districts subject to them. § 199—201.
  c. Actual range of a single shock. § 202—204.
  d. Attendant phenomena of fracture, and elevation or depression of the surface. § 205—209.
D. By volcanic eruptions.
  a. Nature of volcanoes. § 210—217.
  b. Products erupted from volcanoes. § 218—220.
  c. Districts presenting active volcanoes. § 221—226.
  d. Communication between distant volcanoes. § 227—228.

II.—Indirect indications of subterranean change.

A. By former alterations of level in volcanic districts. § 230—231.
B. By marks of extinct volcanic action.
  a. In extinct volcanic cones. § 232—235.
  b. In accumulations of known volcanic products, § 236.
C. By alterations of level in districts not volcanic.
  a. Elevation of various coast lines. § 237—238.
  b. Depression of large areas. § 239.

185. Flames have in many places been observed to issue from the ground from clefts in the earth, which appear to allow the escape of gases from some depth. When such gases are carburetted hydrogen, or hydrogen, they readily take fire, and long continue to burn.

* The authorities chiefly consulted in this chapter have been "D'Archiac's Histoire des progrès de le Geologie," tome i.; Bischof's "Geologie;" Von Hof's "Geschichte der Erdoberfläche;" Lyell's "Principles of Geology;" De la Beche's "Manual," "Researches," and "How to Observe;" Beudant's "Geologie," Humboldt's "Cosmos" and "Aspects of Nature," and Dr. Daubeny's "History of Active and Extinct Volcanoes."

When sulphuretted hydrogen, sulphurous vapours, or muriatic acid, they are either not inflammable, or burn with a flame hardly seen by daylight, and, therefore, not so likely to be noticed; and when carbonic acid, which is the most common, and is emitted in great abundance in many places, they at once extinguish flame and destroy animal life. Carburetted hydrogen has long been emitted from the ground, and is actually used in China for culinary purposes and illumination; and recently gas obtained in the same way has been used in the village of Fredonia in the State of New York, in America.

There are several places where this gas issues from the ground on the south of the great chain of lakes of North America. Three miles south of Lake Erie, it issues from a blue schist, and a bore-hole is sunk to about 23 feet in schists and bituminous substances, whence the gas is conducted by tubes to a gasometer, and afterwards conveyed to different parts of the town.

In the neighbourhood of Newcastle-on-Tyne, in England, where the coal beds in some places contain a large quantity of this gas, it is conducted from the deep working of the mines to the surface, and there burnt, merely to avoid the danger of its escape into the works. It is evident, that in these cases, the depth from which the gas is obtained is very small, but other examples are recorded where a constant emanation occurs from great depths, and in the neighbourhood of volcanoes. Such are the *fumaroles* (eruptions of aqueous vapour) and *solfataras* (eruptions of sulphurous vapours) so often described, and the *hornitos* or little ovens of the Mexican volcanic plains.

186. Flames issue from the ground, unaccompanied by any true volcanic phenomena, at what are called *salses*, at Sassuolo in the Apennines, about mid way between the Adriatic and Massa on the Mediterranean coast; and many other similar appearances are described in Tuscany. Eruptions of mud from small orifices, also called salses, are described as occurring in Java, where gas at a high temperature, mingled with the vapour of water, has acted and continues to act powerfully on the surrounding solid matters, disintegrating and decomposing them, and forming many new compounds, and sometimes being accompanied by true eruptions of boiling acid mud.

Very remarkable and destructive floods of hot mud are on record, not only in Java but in Peru, where in the year 1698, the volcano of Carguaraizo gave forth a torrent of mud that covered nearly 80,000 acres of ground, and in 1797, an entire village near Rio Bambo was buried under a similar mass. In most cases the mud itself has certainly not been brought from any considerable depth, since it contains organic matter, and abounds in the cases of infusorial animalcules.

Greece and Asia Minor, and also various districts in the Crimea, have been found to furnish examples of a similar kind of subterranean action, and it is supposed to occur in the bed of the sea of Azof. At Carthagena in New Spain, in some parts of Hindostan, and elsewhere, almost the same appearances are connected with recent volcanic action; and Humboldt suggests that they present an image of the constant but feeble activity of the interior of the globe. They are in some cases continuous and incessant, and in others occur only at intervals of greater or less magnitude.

187. "The phenomena of mud volcanoes are deserving of more attention than geologists have hitherto given to them; their grandeur has been overlooked, because, of the two phases presented by them, it is only the second, or calmer state, lasting for centuries, which has been usually described; but their origin is accompanied by earthquakes, subterranean thunder, the elevation of great districts of country, and lofty jets of flame of short duration. When the mud volcano of Jokmali, on the peninsula of Abscheron, east of Baku, on the Caspian Sea, was first formed on the 27th of November, 1827, flames blazed up to an extraordinary height for a space of three hours, and during the following twenty hours they rose about three feet above the crater from which mud was ejected. Near the village of Baklichli, west of Baku, the column of flame rose so high, that it could be seen at a distance of twenty-four miles. Enormous fragments of rock, torn doubtless from great depths, were hurled to a distance around. Similar fragments are seen around the now tranquil mud volcano of Monte Zibio, near Sassuolo, in Northern Italy. For fifteen centuries the Sicilian salse near Girgenti (Macalubi), described by the ancients, has continued in the secondary stage of activity; it consists of several conical mounds, from eight or ten to thirty feet high, subject to variation both in form and height. Streams of argillaceous mud, accompanied by periodical disengagements of gas, flow from very small basins containing water, at the summits of the cones. In these cases the mud is usually cold, but sometimes it has a high temperature, as at Damak in the province of Samarang, in Java. The gaseous eruptions, which are accompanied by noise, vary in their nature, consisting sometimes of hydrogen gas mixed with naphtha, sometimes of carbonic acid, and even occasionally of almost pure nitrogen, as Parrot and myself have shown in the peninsula of Taman, and in the South American volcancitos of Turbaco."*

188. When large quantities of bituminous matter occur near the earth's surface they occasionally yield naphtha springs, petroleum, and other forms of liquid bitumen, and these if set on fire continue to burn for a long time, and present on a small scale some of the phenomena of true volcanoes. They have been designated *pseudo-volcanoes*; and a remarkable instance at Baku, near the Caspian Sea, has been long known and frequently described. Similar examples occur at Rangoon, near the delta of the Irrawaddi, and also in China, in Japan, and in North America. The extraction of the bitumen in many of these localities is a matter of economic importance, but we are here only considering the facts as far as they relate to changes produced at the earth's surface.

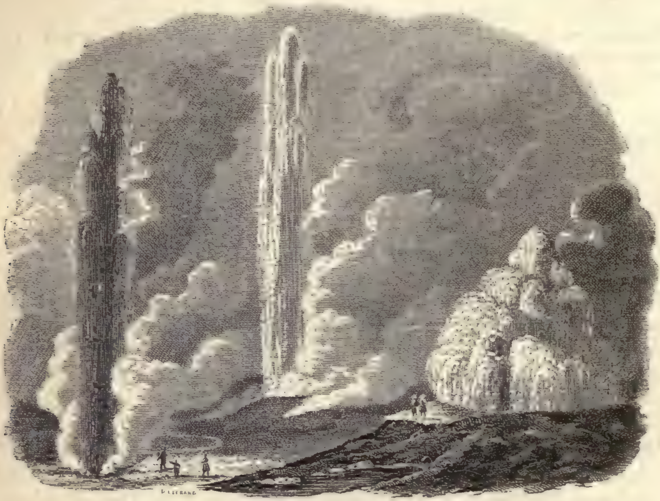
189. Eruptions of heated water are common in many volcanic districts, but nowhere so remarkably as in the Geysirs, or boiling fountains of Iceland, and we append in the next paragraph the latest and most authentic account of these to which we have access. Other cases of boiling springs have been described in Java, Manilla, and in the circular island of St. Paul, in the East Indies, and also in the volcanic regions of Central and South America.

190. In a plain about eight miles in breadth, extending from the foot of the Blafyell to the sea-shore, and connecting itself with the flat moorland of the coast, lie the springs of the Great Geysir, at the foot of a hill composed of slaty phonolite and grey trachyte. According to all appearance, this plain, which has scarcely a perceptible inclination to the sea, was once a broad fiord, reaching as far as the jagged

* "Cosmos," *ante cit.*, vol. i. p. 212.

mountains of the Yarthettur, and the Blafyellshalls. It is clothed with a thick green carpet of meadow ground, and many larger or smaller springs wind like silver ribbons through the grass, sometimes hiding between high banks, then again coming in sight. To the east and south-east, are seen ranges of flat hills and mountains, among which can be distinguished the cone of Hecla ; on the opposite side, behind the Langafyell, the Byarnefyell, higher and steeper, and mostly veiled in dark blue clouds, clothed at its foot with grass, but at the top showing naked crags, on which lie bare strata of trap-rock and palagonite. From a considerable distance the traveller perceives, at the foot of the Langafyell, light clouds of steam rising out of the ground, or sometimes thick columns of smoke whirling upwards in the air, but he soon finds himself in the midst of a complicated system of boiling springs, which break forth from a volcanic chasm, extending in the direction of north-north-east. The valley of the Geysir is mostly filled with a new alluvium, which has here and there undergone a subsequent elevation, extending northwards from the spring, in a broad ridge. Through this soil, which has been gradually overlaid by a thick stratum of siliceous sinter, the deposit from the springs, the Geysir bursts forth, and from the horizontal beds of this deposit, there has formed in various proportions round the

Fig. 22.



The Geysirs of Iceland.

Geysir and smaller fountains, a flattened cone, in the midst of which is a perpendicular cylindrical funnel of larger and smaller diameter. In ordinary circumstances, the basin of the Geysir is filled with crystal-clear sea-green water, of the temperature of 180° Fahr., and it flows in three small channels over the eastern slope of the cone. After some time, a sound, as of subterranean thunder, can be distinguished, resembling that made by a volcano during an eruption, and then a slight tremulous motion may be perceived on the rim of the fountain. When this has lasted some seconds it ceases perhaps for a time, and then begins again with increased force, the water in the basin begins to swell, and the surface becomes convex, and at the same time great bubbles of steam rise to the surface and burst, throwing up the boiling water some feet high. Then it is again still, and the whole fountain is enveloped in

clouds of steam. This phenomenon is repeated at regularly recurring intervals of an hour and twenty minutes to an hour and a half, perhaps for a day, until it suddenly assumes a different character. A heavier thunder is heard below ; the water swells violently, and begins to heave and dash in the strongest agitation ; and after a few minutes, there shoots up a column of water dispersing at the summit into dazzling white foam ; this has scarcely reached to a height of from 80 to 100 feet, when, before its drops have had time to fall to the ground, a second, and third follows, and rises still higher. Larger and smaller jets now shoot forth in all directions, some sideways in arches, others perpendicularly upwards, with a loud hiss like that of a rocket ; enormous clouds of steam roll upwards ; then comes a loud detonation from below, followed by another column of water higher than any of the preceding ones, and mingled with stones ; and after the phenomenon has lasted for a few minutes, the whole falls and vanishes like the fantastic pageantry of a dream. Before the clouds of steam have had time to disperse, or the boiling water to run off the sides of the cone, the basin which had seemed full to the brim, appears almost dry, the water having sunk nearly 3 feet.*

191. Besides these sources of water at a boiling temperature, there are also many instances in various parts of the world where water rising in springs from below the stratum of invariable temperature (see § 111), conveys to us some information concerning the condition of the interior, and usually has a temperature greater in proportion to the depth of the source, if that can be traced. Such water also comes to the surface charged with mineral substances, including gases, which are often sufficient to give a very distinct character to the water, rendering it, indeed, useless for ordinary culinary purposes, but valuable in medicine, and in the treatment of various diseases. Thermal and mineral springs, as such sources are called, have thus become of considerable economic interest, and are noticed and described with some attention. Any spring of water containing mineral substances in solution or suspension, and having a uniform temperature throughout the year, above the mean temperature at the surface, may be considered to belong to this group, but those only that present distinct and striking phenomena can be noticed in the brief sketch here attempted.

192. Generally, but not always, hot springs are situated near either recent or ancient volcanoes, as those on the slopes of Etna and Vesuvius on the one hand ; and those at Töplitz, Pesth in Hungary, Auvergne, and the Euganean hills, on the other. Those in the Eifel, and the Pyrenees, and others in the Alps, besides many more in similar districts, have evidently relation to some local conditions independently of present volcanic force. Many, indeed, as the hot springs at Bath, those of Buxton, and elsewhere in Derbyshire, and others, cannot be traced at all to volcanic agency, commonly so called, but they exist where great mechanical disturbances and disruptions have occurred in the rocks through which the water passes.

193. Mineral waters having a temperature above the mean annual temperature of the surface generally contain nitrogen, sulphuretted

* Von Waltershausen, "Skizze von Island."

TABLE OF SOME PRINCIPAL THERMAL SPRINGS.

Position and name of the spring.	Elev. in ft. above the sea in 100 ft.	Mean annual temperature.	Temperature of hottest spring.	Cubic feet evolved per 24 hours.		Total solid ingredients in a pint of water.	Gaseous contents in a pint of water in cubic inches.	Nature of the most active and abundant mineral ingredients.
				Water.	Gas.	Grains.		
Bath, England	0	49°	115°	28,339	222	15·000	Carbonic acid 1.2 ..	Mur. of lime and magn., Iron.
Buxton, do.	4	do.	82	13,500	$41\frac{2}{3}$	1·875	Carbonic acid 0·187; Nitrogen 0·580	Mur. of magn. and soda.
Bertrich, Eifel	4	50	90	7,240	?	18·267	Carbonic acid ? ..; Sulphur. hydrogen	Carb. and sulph. of soda.
Boriel, Lower Rhine .. .	4	do.	$171\frac{1}{2}$	?	?	34·000		Mur. carb. and sulph. of soda.
Ems, Nassau	3	do.	131	12,400	?	28·900	Carbonic acid ?	Do.
Wiesbaden, Nassau	3	do.	158	84,092	?	57·590	Do. ?	Mur. of soda, lime, and potash.
Kissingen, Bavaria	6	do.	67	48,034	?	169·000	Do. ?	Mur. of soda.
Carlsbad, Bohemia	11	do.	167	111,715	?	49·600	Do. 11·85..	Sulph. and carb. of soda.
Wildbad, Baden	13	51	98	?	?	3·590	Do. 12·00; Nitrogen 79·25; Oxygen 8·25	Mur. carb. and sulph. of soda.
Gastein, Tyrol	30	do.	$117\frac{1}{2}$	100,080	?	2·718	Carbonic acid	Sulph. of soda mur. soda and potash.
Plombiéres, Vosges	13	do.	$146\frac{3}{4}$	9,000	?	?	?	Mur. and sulph. of soda magn. and lime.
Mont Dor, Central France	34	56	108	12,780	?	11·400	Carbonic acid	Carb. mur. and sulph. of soda.
Chaudesaigues, Cantal	?	do.	174	307,188	?	14·500	?	Carb. and mur. of soda, magn. and lime, and ox. iron.
Vernet, Pyrenees	17	60	132	2,455,668	?	14·311	?	Sulphuret of sodium, and soda, caustic and with sulphuric acid.
Leuk, Switzerland	47?	49	123	161,364	?	21·470	Carbonic acid	Sulph. of lime magn. and soda.

hydrogen, or carbonic acid gases, and a variable proportion of certain salts, of which muriates, carbonates, and sulphates of lime, magnesia, soda, or potash, are the most active and abundant. They also contain iron very frequently, and occasionally a small proportion of some one or more of the following substances:—ammonia, iodine, bromine, fluorine, phosphorus, lithia, strontia, barytes, and manganese. As affording the best means of forming an idea of the relative proportion of these, a table is appended selected from that given by Dr. Daubeny in the 2nd edition of his work on Volcanoes.

194. Besides those in the table may be mentioned the springs of St. Gervais, in Savoy, which have a temperature of 106° Fahr., and contain 45½ grains of sulph. soda and lime, and mur. soda and magnesia in each pint of the water; the spring of Acqua della Bolenta, in Piedmont, temperature 107° Fahr.; those of Abano, near Padua, 121°; the Baths of Nero, also 121°; spring at Ischia, varying from 83½ to 94½°; various springs in the north-western provinces of Spain, ranging from 192° to 107°; others, in Southern Spain (Murcia) 104° to 113°, Fahr.; several in Portugal from 75° to 95°; and the following, also in Portugal, all above 100° Fahr.—Monçao, near Ucana (province of Minho), 109½°; Torres Vedras (Estremadura), 111°; Lagiosa, near Viseu (Beirá), 120°; Guimarens (Minho), 138°; Chaves, near Braganza (Tra los Montes), 141·8°; and San Pedro Dosul near Viseu (Beira), 153½°.

In Greece, there are springs near the Pass of Thermopylæ, whose heat is 113°, besides several others of lower temperature; and in European Turkey, several groups, one of which, near the Balkan, has a temperature of 162½°.

Several warm springs have been discovered in North America, ranging from 70° to 110°, Fahr., and there are certainly many much hotter which have not yet been ascertained with sufficient accuracy to enable us to record them here. South America exhibits numerous examples of similar phenomena, and they have been met with in several islands of the Australasian Archipelago.

In addition to the substances mentioned in the preceding table, many of the warm springs contain silica in considerable abundance.

195. In various parts of the world, and at various times, there have been felt movements of the superficial crust of the earth, consisting for the most part of one or more rapidly succeeding undulations, accompanied often by sounds, and traceable distinctly in some particular direction, chiefly linear, taking time to proceed from one point to another. They are called *earthquakes*, and are recognised phenomena in all volcanic countries, but occur also in districts which present no mark whatever of volcanic origin, and no trace of volcanic products. The undulations vary greatly in number and frequency, both on each particular occasion of earthquake disturbance and in a given time, but they seem much more frequent and more widely traceable than has been generally supposed.

196. The movements of the earth in those shocks that have been felt in volcanic countries, are described as of three kinds, namely —

1st. *The Undulatory Motion*, which takes place horizontally, and heaves the ground successively upwards and downwards, proceeding onwards in a uniform direction.

2nd. *The Succussive Motion*, in which the ground is heaved up in a direction more or less approaching to the perpendicular, as happens in the explosion of a mine.

3rd. *The Vorticose Motion*, which seems to be a combination of the two preceding

ones, several undulations taking place contemporaneously, and thus interfering one with the other, so that during its continuance, the surface of the land is tossed about somewhat in the same manner as that of the sea is during the prevalence of a storm, when a number of billows, travelling in different directions, strike one against the other, and thus produce every possible complexity of movement.

Of these three kinds of earthquake-shocks, the first are the most common and the most harmless. From the second, that of *succussion*, more is to be apprehended ; but the vorticose movement is the one which has been felt in the most violent and disastrous catastrophes on record.* (See § 209.)

197. A hollow noise often accompanies or precedes the shock of an earthquake, but is occasionally heard some time *after* it. At other times no sound whatever has been recognised. Thus, the great earthquake of Riobamba in 1797 occurred without noise ; and on the other hand, there was heard on one occasion in the Caraccas a loud noise resembling thunder without any earthquake ; but at the same moment that a volcano in the Island of St. Vincent, more than 600 miles distant, was pouring out a prodigious stream of lava.† These phenomena of sound are described as very striking, and also very variable, but they all seem to prove that the cause of the disturbance with which they are connected is very deeply seated, and extends very widely over the internal surface of the earth's crust.

198. Observations made on slight earthquake shocks in Northern Europe are highly interesting as showing something of the extent and nature of such undulations. We are indebted to M. Perrey for collecting and comparing the accounts of a number of observations made in Europe and Asia Minor, and other records have been kept of the movements felt in Scotland during several years past. M. Perrey has succeeded in obtaining accounts of no less than 3432 distinct earthquakes that have occurred in Europe and the adjacent parts of Asia and Africa, between the commencement of the fourth century and the year 1844 inclusive. Of these the dates of nearly 3000 are known and they have been found to be thus distributed in the different months of the year :—‡

December	300	
January	336	or 911 in the winter months.
February	275	
March	265	
April	235	or 710 in the spring do.
May	210	
June	201	
July	216	or 653 in the summer do.
August	236	
September	221	
October	252	or 705 in the autumn do.
November	232	
	2979	

* Daubeney on Volcanoes, 2nd edition, p. 509. † "Cosmos," vol. i. p. 195.
‡ "Histoire des Progrés de la Géologie," vol. i. p. 606.

There have thus been 1,712 recorded eruptions between the 1st of October and the 31st of March, and only 1,335 from the 1st of April to 30th of September. This result is sufficiently remarkable, and it also appears that in each particular year the same order was observed; but it must not be regarded as important with respect to the general phenomena of earthquakes in other districts, beyond illustrating the fact that some seasons and periods are more subject to disturbances than the rest of the year, or, in other words, that earthquakes exhibit a certain amount of periodicity.

199. In addition to all known volcanic districts, which are without exception localities subject to earthquake action, distinct shocks often of very small amount, and not sufficient to do any material damage, have been recorded as occurring in almost every country in Europe. There is generally but little connexion to be traced between those of distant countries.

In Scandinavia, M. Keilhau has recorded several shocks, and there seems no doubt that, with proper instruments, the number within a given period would be found much greater than is yet known. On the 31st of August, 1819, one occurred, having a wide range, and there were several between the 7th of March and 29th of November, 1827. In January, 1845, an earthquake was felt at Arendal, in Norway and in April, 1841, slight shocks were noticed in Jutland.

Within the British Islands, but especially in North Britain, a large number of recent earthquake observations have been made, proving frequent but very small oscillations in certain districts. Small movements near the coast, producing a slight shake, were felt in Cornwall, in July, 1843; and on the 22nd of December, in the same year, considerable shocks occurred in Brittany. Various parts of France and Germany have been subjected to slight disturbances, which are chiefly felt in the valleys of the great rivers. North Italy has had many, some being of great magnitude, besides an infinity of smaller extent. Spain, also, has had several, and with regard to Portugal, one of the most remarkable earthquakes on record destroyed the city of Lisbon, in 1755, and has long been referred to and described as exhibiting phenomena of the highest interest and extending over an extent of country so wide that its source must have been very deeply seated and of corresponding energy (see § 203). Both South-eastern and North-eastern Europe, as well as Hungary, are frequently subject to slight disturbances of the surface, no less than 318 having been recorded as occurring in the valley of the Danube since the commencement of the fourth century, while Syria and Asia Minor have been long exposed to much more violent shocks. North Africa partakes of the movements of the northern and eastern shores of the Mediterranean. Russia seems to be the country where there occur the smallest number of earthquakes, and in the Ural Mountains they are almost unknown.

200. While the whole of Europe and the adjacent countries are thus manifestly acted on by subterranean forces, which are with few exceptions sudden and momentary, and very often extremely small both in local effect and extent, Central, Eastern, and Southern Asia, and the islands between Eastern Asia and the Australasian Archipelago, are from time to time subjected to more continuous, more severe, and far more extensive concussions, often shaking and destroying wide tracts. In those countries also, whenever careful observations are made, the annual number of small shocks is found to be very considerable.

The whole chain of the Andes, and much adjacent country, but especially the central Cordilleras and Mexican Andes, are exposed to

every kind of subterranean disturbances. The length of the line along which these phenomena are both common and violent is not less than 1000 miles, but the lateral extension does not seem very great, although more considerable on the side of the coast than towards the interior. North America, especially in the valley of the Mississippi, is also frequently shaken; and the islands of the Pacific are many of them known to undergo a like series of movements.

201. On the whole it appears that the whole or some parts of every large tract of land, besides numerous islands and portions of the sea bottom, are exposed to the disturbing forces we are now considering, for whenever the sea bottom is disturbed, and probably on few other occasions, waves of translation are generated apart from the ordinary action of tides and marine currents, and such waves are extremely frequent on many coasts. It cannot, therefore, be doubted that there is everywhere beneath the surface some tendency to change, however slight, and that this tendency is shown by paroxysmal movements at variable but sometimes considerable depth beneath the surface, having little relation with each other, though not unfrequently repeated in nearly the same direction and over the same area. Many districts in which the shocks of earthquakes often recur are unquestionably those in which volcanoes act; and certain relations have been established between volcanic eruptions and earthquake movements, which we shall allude to presently, and which should on no account be lost sight of. Still there are so many, and such important exceptions to these apparent relations, and the subject is still so obscure, that many observations are needed before a satisfactory conclusion can be arrived at.

202. The actual extent or range of the shock in each particular case is a matter which we must next consider, and it will be found to vary almost infinitely, the smaller movements being only just traceable, and not affecting at the same time more than a single village or a few square miles, while the larger shocks range not only over tracts many hundred miles in length and breadth, but across wide oceans, and from one continent to another. The latter kind are, however, comparatively rare; and in describing one or two a sufficient idea will be obtained of all the more important facts. In most of the movements of small extent and frequent recurrence little injury is done, the disturbance not affecting more than a single building or part of a building. In others, however, the shake and undulation are sufficient to induce the natives of the countries where they occur to erect their habitations, and even their public buildings, with a view to the chance of shocks of moderate extent, although no style of construction can defend a town against the effects of large and more serious disturbances.

203. The following account of the great earthquake that destroyed

Lisbon on the 1st of November, 1755, will be read with interest, and well describes the chief phenomena. The city had suffered greatly by an earthquake in 1531, and much damage had then been done by an accompanying wave, described as a great swell. In that case, no doubt, as in the other, the disturbance had affected the bed of the ocean, elevating a portion of the water, and forming a vast wave of translation, which coming in after the earth-wave, served to complete the mischief the latter undulation had commenced. We extract the account from a work published in 1757.

"There was a sensible trembling of the earth in 1750, after which it was excessively dry for four years together, insomuch that some springs formerly very plentiful of water, were dried, and totally lost, at the same time the predominant winds were east and north-east, accompanied with various, though very small, tremors of the earth. The year 1755 proved very wet and rainy, the summer cooler than usual, and for forty days before the great earthquake clear weather, yet not remarkably so. The 31st of October, the atmosphere and light of the sun had the appearance of clouds with a notable obfuscation. The 1st of November, early in the morning, a thick fog arose, which was soon dissipated by the heat of the sun, no wind stirring, the sea calm, and the weather as warm as in England in June or July. At 35 minutes after 9 o'clock, without the least warning, except a rumbling noise, not unlike the artificial thunder at our theatres, immediately preceding, a most dreadful earthquake shook by short, but quick vibrations, the foundations of all Lisbon, so that many of the tallest edifices fell that instant. Then, with a scarcely perceptible pause, the nature of the motion changed, and every building was tossed like a waggon driven violently over rough stones, which laid in ruins almost every house, church, convent, and public building, with an incredible slaughter of the people. It continued in all about six minutes. At the moment of the beginning some persons on the river, near a mile from the city, heard their boat make a noise as if run aground or landing, though then in deep water, and saw at the same time the houses falling on both sides the river. Four or five minutes after the boat made the like noise, which was another shock, which brought down more houses. The bed of the Tagus was in many places raised to its surface. Ships were drove from their anchors, and jostled together with great violence; nor did the masters know if they were afloat or aground. The large new quay called Cays Depreda, was overturned, with many hundreds of people on it, and sunk to an unfathomable depth in the water, not so much as one body afterwards appearing. The bar was seen dry from shore to shore; then suddenly the sea, like a mountain, came rolling in, and about Belem Castle the water rose fifty feet almost in an instant; and had it not been for the great

bay opposite to the city, which received and spread the great flux, the low part of it must have been under water. As it was, it came up to the houses, and drove the inhabitants to the hills. About noon there was another shock, when the walls of several houses which were yet standing, were seen to open from top to bottom more than a quarter of a yard, but closed again so exactly as to leave scarce any mark of the injury.

"This earthquake came on three days before the new moon, when three-quarters of the tide had run up. The direction of its progress seems to have been from north to south nearly, for the people on the river, south of the town, observed the remotest buildings to fall first, and the sweep to be continued down to the water's side. Few days passed without some shock for the space of an ensuing year. October 10th, 1756, at 11 o'clock at night, there was one which threw down the greatest part of an hotel in the parish of St. Andrew; and the 1st of November, 1756, being the anniversary of the fatal tragedy of this unhappy city, another shock gave the inhabitants so terrible a fresh alarm, that they were preparing for their flight into the country, but were prevented by several regiments of horse placed all round by the king's orders."

204. The earthquake of Lisbon was not confined to the spot at which the chief mischief was effected. At Colares, at a distance of about 20 miles, three distinct shocks were felt on the 1st of November, accompanied by the emission of a quantity of smoke, and the fountains were affected. At Coimbra, several buildings were destroyed; at Oporto the shocks were felt for six or seven minutes, during which, everything shook and rattled; the river also being much affected. In Spain, at and near Cadiz, the destruction was only inferior in importance to that experienced at Lisbon, the shocks commencing some minutes after 9 A.M., and at 11, a wave coming in described as 60 feet higher than common. At Gibraltar, a tremulous motion was felt about ten minutes after ten o'clock, and at Madrid at five minutes before ten o'clock, the indications in each case very decided, but the result not very destructive. Malaga felt a violent shock, and at Seville the earthquake damaged the cathedral, and killed several people. All Spain was more or less affected.

Out of the Peninsula, France was affected in several places on the same day, and at various parts of the Normandy coast, at about 11 o'clock, much disturbance was observed in the motion of the ocean. Near Angouleme, a subterranean noise was heard, after which the earth opened and discharged a torrent of water mixed with red sand. In Italy, earthquakes were felt at Milan, and at Turin, and the waters of the Mediterranean were greatly disturbed, especially about the island of Corsica, where there was also a slight shock. In Switzerland, great agitation was noticed, chiefly in the waters of the Lakes of Geneva, Neufchâtel, and Zurich.

While these parts of Europe were disturbed, movements were also felt in Germany, where the waters of several of the principal rivers were disturbed, and some towns, as Strasburg and Stutgard, suffered slightly from earthquake shocks. The same took place in Holland, Norway, and Bohemia, the indications of disturbance being in all cases chiefly seen in the rivers, and in deep springs of water, which were evidently shaken, and often rendered muddy. This occurred especially, at Töplitz, at Amsterdam, Haarlem, Leyden, Rotterdam, and the Hague.

The British Islands experienced this shock in various ways, but chiefly also in the disturbance of rivers, ponds, and springs of water. Shocks, however, were distinctly felt in the lead mines of the Peak of Derbyshire, and near Reading in Berkshire.

Various movements of the water were seen along the coast, but most distinctly on the southern and eastern shores of England, and also in Loch Lomond and Loch Ness, in Scotland, and in the lakes of Cumberland. On the coast of Ireland the same phenomena were observed, and at Cork there were two shocks of an earthquake. The amount of rise of the water varied considerably, but seems to have been about equivalent to a general upheaval of the bed of the ocean, lake, or stream, to an extent of from 10 to 30 inches in vertical height. The time of the disturbances in England was, in different places, from half-past 9 to 11 o'clock, although with some exceptions.

Besides these places in Europe, many parts of Africa were affected, especially on the Mediterranean coast, Algiers, Morocco, Tangier, and Tetuan, being all injured by severe earthquakes. In the Atlantic the Island of Madeira and the Canary Island suffered; the water rose in the sea at Antigua and Barbadoes; and in the open ocean, several ships were violently agitated by sudden and considerable waves.

It has been observed, that besides a multitude of other places, this great earthquake was very sensibly felt in Europe, at Fahlun in Sweden; in Africa at the capital of the Empire of Morocco; and in America at the Island of Barbadoes. Between Fahlun and Barbadoes are 70° of a great circle, nearly; between Barbadoes and Morocco 49°, and between Morocco and Fahlun, 33° of the like degrees. Now these constitute the three sides of a spherical triangle, to which, if a well-known theorem be applied, it will be found, that the effects of the earthquake of the 1st of November, 1755, were distributed over very nearly 4,000,000 of English square miles of the earth's surface; a most astonishing space, and greatly surpassing any thing of this kind ever recorded in history.*

205. The permanent results of earthquake movements, or of the transmission of a wave through the earth in any district, may be of two kinds; either a mere cracking and splitting of certain rocks, and a consequent removal to a short distance of those which were in doubtful equilibrium; or the positive elevation or depression of an area more or less extensive.

It is chiefly in volcanic districts that the former and least considerable result—that of splitting and slightly upheaving or depressing small portions of the surface has been observed, and examples figured in the annexed diagrams, figs. 23, 24, 25, will enable the

Fig. 23.

Fig. 24.

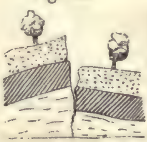


Fig. 25.

Alterations of level produced by Earthquakes.

reader to understand the nature, and something also of the relative extent of the disturbance. A chasm thus formed in Calabria has been found to measure as much as a mile in length, 105 feet in breadth, and 30 feet in depth. Another was three-quarters of a mile long, 150 feet broad, and above 100 feet deep, and a third a quarter of a mile long, 30 feet broad, and 225 feet deep.†

* "History and Philosophy of Earthquakes," p. 333.
† Lyell's "Principles," *ante cit.*, p. 459.

206. "Sir W. Hamilton was shown several deep fissures in the vicinity of Mileto, which, although not one of them was above a foot in breadth, had opened so wide during the earthquake as to swallow an ox and nearly one hundred goats. The Academicians also found, on their return through districts which they had passed at the commencement of their tour, that many rents had, in that short interval, gradually closed in, so that their width had diminished several feet, and the opposite walls had sometimes nearly met. It is natural that this should happen in argillaceous strata ; while in more solid rocks, we may expect that fissures will remain open for ages. Should this be ascertained to be a general fact in countries convulsed by earthquakes, it may afford a satisfactory explanation of a common phenomenon in mineral veins. Such veins often retain their full size so long as the rocks consist of limestone, granite, or other indurated materials ; but they contract their dimensions, become mere threads, or are even entirely cut off, where masses of an argillaceous nature are interposed. If we suppose the filling-up of fissures with metallic and other ingredients to be a process requiring ages for its completion, it is obvious that the opposite walls of rents, where strata consist of yielding materials, must collapse or approach very near to each other before sufficient time is allowed for the accretion of a large quantity of veinstone."*

207. "The undulations in earthquakes have been examined with tolerable accuracy, in respect to their direction and intensity, by means of pendulums and sismometers, but in their characters of alternation and periodical intumescence, they have by no means attracted sufficient attention. In the city of Quito, which is situated at the foot of a still active volcano—the Rucu-Pichincha—and at an elevation above the sea of 9539 feet, and which possesses fine cupolas, high-roofed churches, and massive houses of several stories in height, I have been often surprised in the night by the violence of the earthquake-shocks ; but these, though extremely frequent, very rarely injure the walls, whereas, in the Peruvian plains, even low dwellings built of reeds, suffer from apparently far slighter oscillations. Natives of those countries, who have experienced many hundred earthquakes, believe the difference to be less in the greater or less duration of the shocks, or the slowness or rapidity of the horizontal oscillation, than in the alternation of motion in opposite directions."†

208. The following is the order of the phenomena of an earthquake occurring at or near the sea, according to Mr. Mallet, who has lately paid careful attention to the physical and mathematical problems connected with these disturbances:—

"First, we have the earth sound-wave, and the great earth-wave, or shock ; the sound-wave through the air ; the sea-wave occurring at the time, called the forced sea-wave ; and the great sea-wave ; all originating at the same moment and produced by one impulse.

"The sound-wave through the earth, and the great earth-wave or shock, arrive first, and are heard and felt on land, accompanied, as far as the beach, by the small sea-wave called the forced sea-wave ; these are almost instantly succeeded by the sound-wave through the sea ; next arrive the aërial waves of sound, and continue to be heard for a longer or a shorter time ; and finally, the great sea-wave rolls in upon the shore.

"The velocity of the land-wave, and that of the accompanying sea-wave being ascertained, it would seem possible to determine the distance (out of sea) from the spot affected at which the earthquake originated. But the former will vary with the nature of the rock through which it is transmitted, for the harder and more elastic the rock is, the greater will be the velocity of the earth-wave produced, and *vice versâ*.

"Now whilst the elasticity of cast-iron is 5·895, that of limestone varies from 2·4 to ·635 ; slate being 7·8 ; Portland stone, 1·57 ; white marble, 2·15. From these data we may calculate that the velocity of the wave-transit per second in

* Lyell, *ante cit.* p. 460. † "Cosmos," *ante cit.* vol. i. p. 192.

Limestone (soft lias) was	3,640	feet or	40	miles per minute.
Sandstone	5,248	„	57	„
Portland stone..........	5,723	„	62	„
Marble................	6,696	„	73	„
Carboniferous limestone ..	7,075	„	78	„
Clay slate..............	12,757	„	140	„

"The observed speed of the great Lisbon earthquake, according to Mitchell, was only 1750 feet per second, the difference being assignable to breaches of continuity and other causes of retardation. The sea-wave, on the contrary, had not one-tenth of that velocity, or did not travel more than 175 feet per second; so that, if the interval of time between the two was, as it is reported, half an hour, the focus of the impelling force would have been about sixty miles distant from the land." *

209. The vorticose movement described as characterising certain earthquake undulations has been explained by Mr. Mallet in a manner far more reasonable than had before been done. He considers that the motion is the same kind in every case, but that "the centre of adherence between the ground and the base of the object moved is, in these vorticose movements, neither directly under the centre of gravity, nor in the plane of motion passing through its centre of gravity, but in some point of the base outside the line of its intersection by the plane; in this case the effects of the rectilinear motion in the plane of the base will be to twist the body round upon its bed, or to move it laterally and twist it at the same time, thus converting the rectilinear into a curvilinear motion in space; the relative amount of the two compounded motions being dependent upon the velocity and time of movement of the base, and upon the perpendicular distance measured horizontally at the surface of adherence, between the centre of adherence and the centre of gravity of the body." †

210. We come next to the subject of volcanoes, which has, indeed, generally been considered as taking precedence of that of earthquakes, but concerning which we shall here say very little, except as it bears upon the important views of physical geography we have endeavoured to impress upon the student in the present chapter. We commence with a description of one of the most striking phenomena on record—the first origin of a volcanic district, and the complete history of the whole volcanic process, as it occurred in the plains of Malpais, in Mexico, about a century ago.

211. The formation of the volcano of Jorullo is, indeed, one of the most extraordinary physical revolutions recorded in the history of our planet, for it exhibits an instance of the elevation of a mountain of scoriæ and ashes 1695 feet above the level of the adjoining plains, in the interior of a continent 106 miles distant from the coast, and very far from any active volcano. The elevation took place in the plain of Malpais on the western side of the city of

* Daubeney on Volcanoes, 2nd edition, p. 525.
† Mallet, "Memoirs of the Royal Irish Academy."

Mexico, the plain being about 2500 feet above the sea, and bounded by basaltic mountains.

In the month of June, 1759, a subterranean noise was heard, and hollow sounds of the most alarming nature were accompanied by frequent earthquakes, which succeeded each other for from fifty to sixty days. From the beginning of September, however, everything seemed to announce the complete re-establishment of tranquillity, when in the nights of the 28th and 29th the horrible subterraneous noise re-commenced, and the frightened Indians fled. A tract of ground from three to four square miles in extent then rose up in the shape of a bladder, and the bounds of this convulsion are still distinguishable from the fractured strata; but so completely is the bladder shape to be traced, that while near its edges the district is only 39 feet above the old level of the plain, the convexity increases towards the centre to an elevation of 524 feet. (See fig. 26.)

Those who witnessed this catastrophe from a neighbouring elevation, assert that flames were seen to issue forth for an extent of more than half a square league, that fragments of burning rock were thrown to prodigious heights, and that through a thick cloud of ashes illumined by volcanic fire, the softened surface of the earth was seen to swell up like an agitated sea. Two rivers precipitated themselves into the burning chasms, and the decomposition of the water doubtless contributed to invigorate the flames, which were distinguishable at the city of Pascuaro, more than thirty miles distant, and situated on an extensive table land nearly 5000 feet above the plains. Eruptions of mud, and especially of strata of clay, enveloping balls of decomposed basalt in concentric layers, appeared to indicate that subterranean water had no small share in producing this extraordinary phenomenon. Thousands of small cones from 6 to 10 feet high, called by the natives *ovens* (hornitos), issued forth from the Malpais; and, although, according to the testimony of the Indians, the heat of these volcanic ovens had suffered a great diminution within fifteen years of Humboldt's visit, he states that he has seen the thermometer rise to 212° Fahr. on being plunged into fissures which exhale aqueous vapour. Each small cone is a *fumarole,* from which a thick vapour ascends to the height of from 22 to 32 feet, and in many of them a subterranean noise is heard, which appears to announce the proximity of a fluid in ebullition.

In the midst of the ovens six large masses, elevated from 300 to 1600 feet each above the old level of the plains, sprung up from a chasm, of which the direction is N.N.E. and S.S.W. The most elevated of these enormous masses is the great volcano of Jorullo. It is continually burning, and has thrown up from its north side an immense quantity of scorified and basaltic lavas containing fragments of primitive rocks. These great eruptions of the central

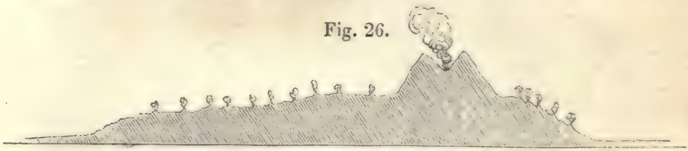
volcano continued till the month of February 1760, but in the following years they became gradually less frequent.

At the time of Humboldt's visit twenty years afterwards, although the subterraneous fire appeared less violent than at first, and the Malpais and the great volcano had begun to be covered with vegetation, they nevertheless found the air heated to such a degree by the numerous small ovens, that the thermometer at a great distance above the ground and in the shade rose to 109° Fahr. This fact proves that there is no exaggeration in the accounts of several Indians, who affirm that for many years after the first eruption the plains of Jorullo, even at a great distance from the ground which had been thrown up, were uninhabitable on account of the excessive heat which prevailed.

The traveller is still shown two rivers bearing the names of those whose waters formerly traversed the plain, and which disappeared on the night of the 29th of September, 1759. At a distance of 6500 feet to the west of the former streams, and in the tract which was the theatre of the convulsions, two rivers now burst through the argillaceous vault of the *hornitos*, making their appearance as warm springs, and raising the thermometer to 186° Fahr.*

The annexed diagram (fig. 26) will give an idea of the mode in

Fig. 26.



Section across the elevated part of the Plain of Malpais.

which the plain was elevated, and the proportionate elevation of the principal hills.

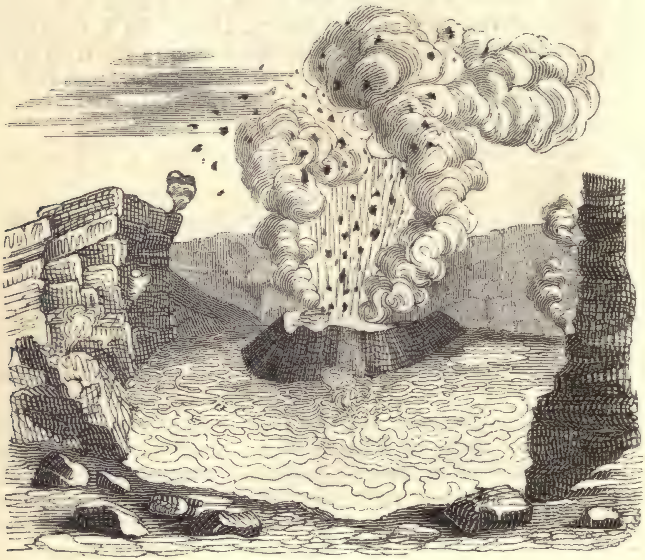
212. A volcano generally may be described as a conical hill or mountain, with a cup-like hollow or *crater* at the summit, from which issue occasionally gaseous and acid vapours mingled with steam; certain scoriaceous rocks of small specific gravity called volcanic ash and pumice, often in the form of fine dust; and at more distant intervals several mineral substances in a state of partial or complete fusion called *lava*. There can be no doubt whatever that a very high temperature obtains at small depths beneath the surface in every active volcanic district; but there seems no sufficient proof of this high temperature being the result of communication with great depths below the surface, or of any volcanic products being other than surface rocks altered by the admixture of alkaline earths, which render them readily fusible. It is, however, certain that there

* From Humboldt's "Nouvelle Espagne," as quoted in Daubeney's work on "Active and Extinct Volcanoes."

exists in many cases free communication underground between volcanoes at great distances from each other, and that earthquake action is checked or prevented in many districts by the occasional eruptions of ashes and lava that take place at a volcanic vent.

213. Volcanoes are rarely isolated, being on the contrary almost always collected into groups, some linear, and others apparently in circular or elliptic areas. (See § 226.) They vary indefinitely in height, some possessing no elevated cone whatever, others being of moderate elevation, while some rank among the very loftiest of the mountains of the globe. The proportionate size of the crater and other details also vary greatly; some craters, as that of Vesuvius, seen in the accompanying sketch (fig. 27), being small, but distinct, and others, as the vast cavity of Kirauea, in the island of Hawaii

Fig. 27.



Crater of Vesuvius in 1829.

(Owhyhee), of enormous magnitude, measuring 16 miles in circumference and 1200 feet in depth.

214. Humboldt says, "The degree of intensity of the upheaving force is shown by the height of the volcano, which varies from that of a mere hill to that of a cone of above 18,000 feet of elevation. It has appeared to me that the height of volcanoes exercises a great influence on the frequency of eruptions, which are far more frequent in the lower than in loftier volcanoes. As instances, I may place in a series —Stromboli, 2,318 feet; Guacamayo, in the province of Quiros (whence detonations

are heard almost daily as far as Chillo, near Quito, a distance of eighty-eight miles); Vesuvius, 3,876 feet; Etna, 10,870 feet; the Peak of Teneriffe, 12,175 feet; and Cotopaxi, 19,070 feet. If we suppose the seat of action to be at an equal depth

Fig. 28.

Map of the Isle of Palma.

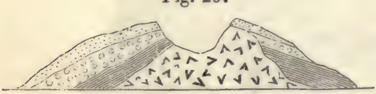
below the general surface of the earth in the case of all these volcanoes, it must require greater force to raise the molten masses in the case of the higher mountains; and it is not surprising that Stromboli, whose elevation is the least considerable, should have been in a state of constant activity for many centuries, and still serve as a flaming beacon for the mariners who navigate the Tyrrhenian Sea, whilst the loftier volcanoes are characterized by longer intervals of repose."*

215. Volcanic districts generally present marked physical features, and the characteristic aspect thus assumed will be best under-

* "Cosmos," vol. i. p. 217.

stood by referring to the annexed physical map of the Isle of Palma (one of the Canary islands), which is reduced from an admirable map prepared by M. Von Buch, and exhibits the central elevated crater and deep furrows or gorges (locally called *barancos*), not infrequent in the sides of recently elevated craters. It is evident by the natural sections afforded in the ravines that the whole island is one of those phenomena described by Von Buch as craters of elevation, the beds all rising towards a central and lofty ridge, as shown in the diagram fig. 29.

Fig. 29.



Section across a Crater of Elevation.

216. The true structure of such volcanoes and volcanic groups is further illustrated in a group of islands in the Greek Archipelago, of which Santorin is the principal. A chart of these islands is given in fig. 30, and a sectional view across them in fig. 31. The large crescent-shaped island of Santorin, and the islands Therasia and Aspronisi, here form the ridge of the half-elevated crater, while the central islands Hiera Nea, Micra Kameni and Phera, are portions of small cones rising above the waves. Of these Hiera was first elevated 186 years before the Christian era, and other small islets in the years 19, 726 and 1427. In 1573 was formed Micra Kameni, and in 1707 Nea Kameni, which was further elevated in 1709, 1711, 1712, &c. Other islands of the Greek Archipelago are formed in the same manner.

Fig. 30.

Fig. 31.

Map and Section of Santorin and the adjacent Islands.

217. As a still further illustration of the structure of volcanoes, and in the case of one of very large dimensions, we may next refer to the subjoined view and profile of Etna and the adjoining district, figs. 32, 33. This view will serve to correct the idea that might

Fig. 32.

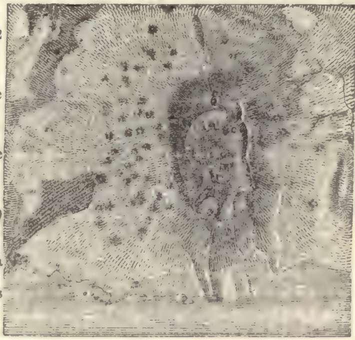
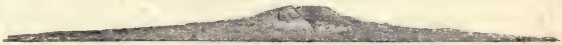


Fig. 33.



View and Profile of Mount Etna and the surrounding Country.

arise on the first consideration of volcanic phenomena, and enable the student to see the small space which the crater and lava currents occupy in proportion to the mass of a large volcanic mountain.

218. It is no part of our plan to dwell at any length on the subject of volcanic products. They include, as has been already said, gases, vapours, ashes and lava ; and after a brief account of remarkable eruptions of the two latter, we shall pass on to another part of the subject. Little doubt can be entertained that these are derived from near the surface, especially since it has been discovered by Ehrenberg that even where no fresh-water exists and no trees grow, the ashes erupted from volcanoes in small islands in the open ocean abound with the remains of fresh-water and terrestrial infusorial animals and plants. In Mexico, Peru, the Isle of France, and many other volcanic regions, the fine volcanic dust has yielded these remains ; and it is only in one place (in Patagonia), that the specimens of tuff and ash examined by M. Ehrenberg have yielded marine infusorial forms. It is generally the siliceous fragments that have been preserved, and these are often half obliterated.

219. As an instance of a volcanic eruption extremely remarkable for the extent of its influence, we may here give, in a few words, an account of what took place in the Island of Sumbawa (one of the

Sunda Islands, lying to the east of Java), in the year 1815. The noise of the explosions accompanying this eruption was heard at the distance of 970 miles to the west, and 720 miles to the east of the island. The ashes were carried 300 miles in the direction of Java, and more than 200 miles northwards towards the Celebes, in sufficient quantity to darken the air; and they were found floating in the ocean to the west of Sumatra, a distance of more than 1000 miles, forming a mass two feet thick, through which vessels with difficulty forced their way.

220. Perhaps the most remarkable eruption on record, in respect of the quantity of lava ejected, was that of one of the Icelandic volcanoes, the Skaptaa Jokul, in the year 1783. On the 8th of June in that year, the unfortunate inhabitants of the south coast of Iceland observed numerous pillars of smoke rising in the hill country towards the north, which gradually collected into a dark band, obscuring the light of day, and advancing in a southerly direction against the wind, showering down vast quantities of sand and ashes. The cloud continued to increase until the 10th, when fire-spouts were seen in the distance, and there were slight shocks of an earthquake. On the 11th the large river Skaptaa, which had lately been much swollen, entirely disappeared; and this accident was fully accounted for on the ensuing day, when a current of lava burst from one side of the volcano, and rushed with a loud crashing noise down the channel of the river, which it not only filled, but overflowed, although in many places the channel was from 400 to 600 feet deep, and 200 feet broad.

The fiery stream, leaving the hills, had its course checked for several days by a lake in the low country; but this also was at length filled up, and the torrent proceeded in two streams, one taking an easterly and the other a southerly direction. The lava continued to flow till the 20th of July, and, following chiefly the course of the Skaptaa, it poured over a lofty cataract, filling up in a few days an enormous cavity, which the waters had been hollowing out for ages.

Up to this time the eastern part of the island had escaped any more serious injury than the showers of ashes, which fell everywhere; but on the 28th of July a further eruption was threatened; and, on the 3rd of August, a thick vapour arising, and the waters disappearing from the bed of another river, the Hverfisfliot, prepared the inhabitants to expect a fiery torrent; which, accordingly, on the 9th, rushed on with indescribable fury, overflowing the country in one night to the extent of more than four miles, and converting their fearful anticipations into still more dreadful realities. The eruptions continued at intervals till the end of August, and closed with an earthquake of extreme violence.

The immediate source, and the actual extent, of these torrents of melted rock have never been accurately determined; but the stream that flowed down the channel of the Skaptaa was about 50 miles in length, by 12 or 15 miles in its greatest breadth, and that in the other river-course, about 40 miles in length, by 7 miles in breadth. In thickness it was very variable; being as much as 500 or 600 feet in the narrow channels, but in the plains rarely more than 100 feet, and often not exceeding 10 feet. Taking the lowest average, and calculating the whole mass, it does not appear that there can have been less than twenty thousand millions of cubic yards, or forty thousand millions of tons of matter, poured out of the bowels of the earth, in a melted state, in the short space of ten weeks, during which the eruption lasted.

It would not give a just idea of the result of this fearful event did we not add, that, at the most moderate calculation, 1300 human beings lost their lives during, or in consequence of the eruption; and that it also involved the destruction of 20,000 horses, 7000 horned cattle, and 130,000 sheep. The fisheries on the southern coast of the island were destroyed; and Iceland has not to this day recovered from the disastrous events of the year of the eruption of the Skaptaa Jokul.

These accounts of a few of the more striking phenomena of recent volcanic action will give some notion of the magnitude and extent of the deep-seated disturbing forces incessantly at work, tending to reproduce those irregularities of surface which are destroyed and levelled by the antagonist force of running water.

221. We pass on now to a very important part of the subject—namely, the actual number and distribution of volcanoes on the earth's surface, for these phenomena are not seen everywhere, nor do they occur like earthquakes without leaving visible traces. There are two kinds, or rather conditions of appearance to be observed and sought for, volcanoes exhibiting indications of either present or past activity. Sometimes the extinction of volcanic influence in a district once manifestly subject to it, is sufficiently marked to leave no question as to the matter, but it is not always so; and many instances are known of volcanoes which have offered no instance of activity within the memory of man, or even the historic period, but which yet cannot be said to be extinct, but are rather dormant. Still there are in Europe many well marked cases of extinct volcanoes, but elsewhere it will be convenient to group together, in explaining their geographical distribution, all the volcanic cones, heaps of ashes, currents of lava, and other volcanic products, regarding them all as indications of recent volcanic activity.

222. In Europe and its dependencies there are active volcanoes only in South Italy, in Sicily and the adjacent islands, in the Grecian

Archipelago, and in the island of Iceland. Extinct volcanoes are found in Auvergne (Central France), in the Eifel, on the Rhine near Bonn (the *Siebengebirge*), in the Black Forest near Switzerland, and in many places in Western Germany between the two last named districts. Other indications appear in Northern Bohemia and North-eastern Bavaria, in Silesia, Moravia, Hungary, Transylvania, Styria, North Italy, Central Italy, Spain and Portugal.

223. In Asia marked volcanic phenomena have been described in most parts of Asia Minor and Palestine—in Arabia, Persia, and the adjoining countries, in Central and Eastern Asia, throughout the Indian Archipelago, in the Japanese and other islands parallel to the east coast, and in Kamtchatka. Many of the most frequent and magnificent exhibitions of volcanic force have occurred in the chain of the Sunda Islands, running along from the Malayan peninsula towards Australia, and thence to New Zealand. Other volcanic districts occur in the Pacific between this archipelago and the coast of America. Africa exhibits numerous volcanic appearances on its northern, and also on its western coast ; and most of the islands in the Atlantic, lying near this continent, are volcanic, as well as some of those in the Indian Ocean.

"The great distance from the sea of the volcanoes of the interior of Asia is a remarkable and solitary phenomenon. Abel Remusat, in a letter to Cordier, first directed the attention of geologists to this fact. The distance in the case of the volcano of Pe-schan to the north, or to the Icy Sea at the mouth of the Obi, is 1780 miles; to the south, or to the mouths of the Indus and the Ganges, 1760 miles ; to the west, 1590 miles to the Caspian in the Gulf of Karaboghaz; and to the east, 1180 miles. The active volcanoes of the New World were previously supposed to offer the most remarkable instances of such phenomena at a great distance from the sea; their distance, however, is only 150 miles in the case of the volcano of Popocatepetl in Mexico, and only 107, 120, and 182 miles in those of the South American volcanoes Sangai, Tolima, and de la Fragua respectively. I exclude from these statements all extinct volcanoes and all trachytic mountains which have no permanent connection with the interior of the earth."*

224. North America presents a broken, but evident chain of volcanoes along its western coast, parallel to and near the Pacific shore. Central America abounds with volcanoes, and the Antilles among the West Indian Islands present everywhere either active or extinct volcanic phenomena. In South America the whole of the Cordillera of the Andes from Mexico to Patagonia, and beyond Tierra del Fuego to the South Shetland Islands, must be regarded as one great volcanic system, the distinct indications of volcanic force being rarely at sufficient distance to allow of doubt as to the existence of a true subterranean communication.

225. The subjoined table will give a general idea of the distribution of volcanoes over the world, and the comparative number of distinct volcanic vents in the different regions. It includes about 400 described examples of active volcanoes, being those of which

* "Aspects of Nature," (English edition) vol. i. p. 88.

there is some evidence of activity within the historic period. Many of them, indeed, have not been known as distinct points of eruption for many centuries; but this does not remove them from the list, as it is very possible for the internal fire to slumber for a much longer period between two epochs of outburst. By giving an idea of the actual distances within which the principal groups are placed, as well as the number in each case, perhaps this table will be found to communicate a tolerably distinct idea of the importance of each group. In many cases, however, the volcanoes are very closely congregated in knots about the centre of the district, while towards its outskirts are only a few cones and craters.

226. *List of the Principal Volcanic Groups with the linear extension of each group.*

	Number of Volcanoes.	Linear extension in Brit. sta. miles.
Atlantic Ocean.		
Jan Meyen Island (Greenland)	2	?
Iceland	8	
Azores	2	?
Canary Islands	7	
Cape Verde Islands	1	
Ascension Island	1	
Trinidad Island	1	
Tristan da Cunha Island	1	
West India Islands	10	450
Mediterranean group		
Lower Italy	2	?
Lipari Islands	2	
Greek Islands	1	
Red Sea	2	
Indian Ocean (west side)		
Bourbon Island	1	?
Mauritius Island	1	
Rodriguez Island	1	
Asiatic Continent		
Western Asia	3	
Central Asia	2	
Eastern Asia	?	
Asiatic Coast		
Kamtchatka group	21	900
Kurile Islands group	18	800
Japan Islands group	23	1700
Bonin and Mariana Islands	9	1000
Formosa	3	280
Luzon and the Philippine Islands	21	1000
Molucca Islands	12	700
North-west coast of New Guinea	4	
Sunda Islands group		
Floris and adjacent Islands to the west as far as Serva	11	600
Sumbawa and others	9	350

	Number of Volcanoes.	Linear extension in Brit. stat. miles.
Java	43	650
Sumatra	7	900
Andaman Islands	5	600
Eastern Archipelago		
Groups of Islands between New Guinea and New Zealand	4	
New Zealand	2	
Friendly Islands	2	
Pacific Ocean		
Hawaii (Owhyhee) group	4	
Society Islands,	1	?
Marquesas Islands	1	
Easter Islands	1	
Galapagos Islands	1	
America		
Aleutian Islands	35	1200
North American Series	10	2000
Mexico	7	700
Guatemala	38	850
Quito	17	450
Peru and Bolivia	12	600
Chile	22	1200
Tierra del Fuego	3	400
Antartic Land	3	

Those groups to which no linear extension is marked are for the most part detached, and exhibit only imperfect communication with any other district. The groups connected by brackets are probably related, but too imperfectly to justify any statement as to their linear extension.

227. One more matter remains for consideration before we quit the subject of volcanoes. It is the nature of the subterranean communication that exists between those of the same or different groups. On this point, as on so many others, we may quote, as of the highest authority, the language of Humboldt, when speaking of the plateau of Quito, where occur the lofty volcanoes of Pichincha, Cotopaxi, and Tunguragua. This, he says, is to be viewed as a single volcanic furnace. "The subterranean fire breaks forth sometimes through one and sometimes through another of these openings, which it has been customary to regard as separate and distinct volcanoes. The progressive march of the subterranean fire has been here directed for three centuries from north to south." He also states, "that in 1797 the volcano of Pasto, east of the Guaytara river, emitted uninterruptedly for three months a lofty column of smoke, which column disappeared at the instant when, at a distance of 280 miles, the great earthquake of Riobamba, and an immense eruption of mud, took place, causing the death of between 30,000 and 40,000 persons." *

228. Facts of similar kind are not wanting in South Italy, tending to prove an open subterranean communication between Etna and Vesuvius and the adjacent vol-

* "Aspects of Nature," *ante cit.* vol. ii. p. 222.

canic vents, since, in nearly 130 recorded disturbances within the last eight centuries, there have occurred few instances of activity from more than one crater at the same time, and not one of any important eruption from the two principal mountains or from any of the smaller cones within a considerable interval. In this way it seems clear that however distinct the volcanoes of the same system may be at the surface, they are in each case parts of one general effect, produced by some deep-seated subterranean cause.

229. Volcanoes have been arranged into two classes, "central volcanoes" and "volcanic chains;" but whether such distinction really exists in nature, we may be allowed to doubt. The former term has been applied to those districts in which a region of volcanic disturbance appears to extend to pretty nearly the same distance in every direction from one central point, while the latter includes instances, of which many are given in the annexed table, where the chain is much further continued in one direction than any other. The volcanoes in the latter case have been compared by Humboldt to a number of vents, either in one line or in parallel lines, connected with some far-extended subterranean fissure, such as we may imagine to have reference to the elevation of a mountain chain. The Peak of Teneriffe is a well-marked example of a central volcano, and so also is the Isle of Palma;* which well illustrates the peculiar appearance presented in such cases. A theory of the formation of volcanoes by elevation at a central point has been based upon this latter view, and explains many of the appearances presented in the Canary Islands and Azores. It does not, however, apply universally, as the volcanic cone is often entirely subordinate to the mountain elevation, and has been established long after the main direction has been given to great and important lines of elevation. It may, indeed, be stated generally, that all the principal volcanic systems are dependent on main lines of direction, or axes of mountain chains, this being the case even for the continental land of the Old World, although so few volcanoes exist there that it is not easy to connect them into one general group. In the New World, the fact is too manifest to require further notice than a reference to the map.

230. The permanent alteration of level of large tracts of land in consequence of earthquake and volcanic action, is a subject which has not yet received full illustration, but that numerous and important temporary changes of level have accompanied or followed the momentary undulations in disturbed districts is beyond question. One of the standard examples of this, referred to by almost every recent writer on geology, is that of the Temple of Jupiter Serapis near Naples, where the temple appears to have been originally built very near the level of the Mediterranean, after which the ground with the temple gradually sank down; thermal waters also issuing in the vicinity, and forming a brackish lake, which left a black incrustation on

* See fig. 28, § 215.

the stone walls as far as the water reached. The lower part of the columns and the floor of the temple seem then to have become covered with a quantity of ashes and tufa, to a thickness of about eight feet, and the depression of the surrounding soil being continued, the incrustation increased, at first irregularly, and perhaps slowly, till at length the sinking was so considerable that the greater part of the columns became submerged, the upper and uncovered portions being exposed to the action of the air, and the part in the sea being eaten into by various marine animals, as far down as there was no covering of ashes and tufa. At length the ground was elevated, and, at the present day, the whole is above the level of the adjacent sea. The movements are still going on, and a change of position has been recognised within the last few years.

Fig. 34.

Temple of Jupiter Serapis.

The following are the oscillations as stated by Lyell ("Principles," p. 494). First,—About eighty years before the Christian era, when the ancient mosaic pavement was constructed, it was about twelve feet above its actual level, or that at which it stood in 1838; secondly, towards the close of the first century after Christ it was only six feet above its actual level; thirdly, by the end of the fourth century it had nearly subsided to its present level; fourthly, in the middle ages, and before the eruption of Monte Nuovo, it was about nineteen feet below its present level; lastly, at the beginning of the present century, it was about two feet two inches above the level at which it now stands in 1838.

231. Subsidence has also been noticed in the low ground subject to earthquakes at the mouth of the Indus, where the same earthquake, during which a large tract was depressed, exhibited also the elevation of a long mound, measuring as much as fifty miles in one direction, and in some places sixteen miles broad.

The valley of the Mississippi has lately undergone some change during long-continued earthquake undulations in 1812. These changes are described by Sir C. Lyell,* and appear to afford a good illustration of the nature of depression. Many districts in South America have been known to present indications of very recent change of level, altering the beds of rivers, and sometimes, by the elevation of a coast line, destroying large numbers of marine animals. The harbour of Port Royal in Jamaica on one occasion sank down nearly

* Lyell's "Principles," *ante cit.* p. 444.

50 feet, and the number of similar examples of alteration of level, immediately resulting from earthquake disturbance, is quite sufficient to prove a connection between the two sets of phenomena.

232. We have already, in a former paragraph (§ 222), in speaking of the volcanoes of Europe, had occasion to notice several which are now in a state of inactivity, and concerning which there is reason to suppose they are really extinct. When, as in the cases there mentioned, the actual condition of the mineral products is such as to indicate considerable antiquity, or when the destruction of form of the ancient volcano has been at all complete, there is, perhaps, little difficulty in determining to which class it should be referred; but in other cases there is often great want of satisfactory evidence. The appearances presented in some well-known instances leave no doubt as to their identity with recognised volcanic results, and it will be desirable to describe some of these. All of them have been perfectly quiet, and free from the disturbances of volcanic action, during, and probably long before, the existence of man upon the earth, but all of them exhibit, with the utmost distinctness, series of volcanic phenomena exactly resembling those which are described as characterising Etna and Vesuvius in modern times.

233. The volcanic district of the Rhine extends for about twenty-four miles from east to west, and from six to ten miles from north to south. The volcanic cones have been forced up through beds of ancient date, and the lava has been poured out around the base of the hills, often extending to considerable distances without much reference to the present configuration of the country. A number of ancient craters, some of which are now lakes, may be observed at different points on each bank of the Rhine, but the walls of these craters are usually made up of cinders and scoriæ, and the deep indentations and fractures of the walls often show the points whence a lava current must once have issued. On the whole, however, the lava seems to have been chiefly erupted through cracks and fissures in the subjacent rocks, and to have been spread evenly over the surface, often in very thin bands.

By far the most important feature of the volcanic district of the Rhine is the great basaltic* platform, partly in the Duchy of Nassau and extending on the right bank of the Rhine, but reaching still further to the east, and forming the hills called the Vogels Gebirge. In the former district the lava beds are covered up in many places by a remarkable bed of lignite, or brown coal, but an area of not less than 1000 square miles of country in the neighbourhood of the Rhine seems to have been in former ages overwhelmed by a flood of lava, probably spread out beneath the waters of an inland lake long since dried up. The thickness of the bed is not very considerable.

* Basalt is the name given to rocks supposed to be ancient lava currents, but now present in places where no volcanic activity is discoverable. The term is further explained in § 236.

234. The district of Central France which in former times was the seat of subterraneous disturbance, reposes on, or rather rises out of, a granite platform; the Mont D'Or, the most conspicuous of the volcanic cones, rising suddenly to the height of several thousand feet, and being composed of layers of scoriæ, pumice stones, and fine detritus, with interposed beds of basalt. A considerable number of minor volcanoes form an irregular ridge on the platform, and extend for about eighteen miles in length and two in breadth. They are usually truncated at the summit, where the crater is often preserved entire, the lava having issued from the base of the hill; and the lavas may be traced from the crater to the nearest valley, usurping the channel of the river, which in some cases has since been re-excavated.

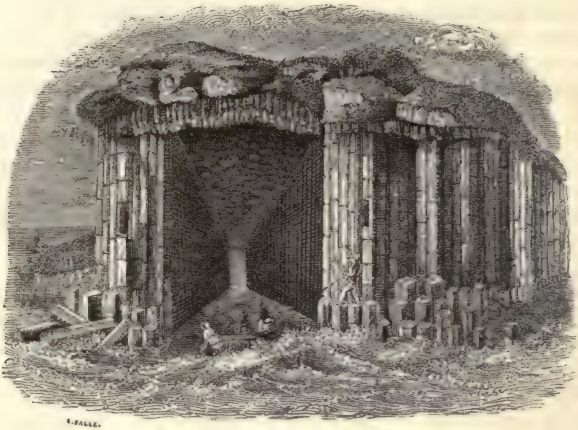
235. In Catalonia the eruptions have burst entirely through Secondary rocks, and the distinct cones and craters are about fourteen in number, but there are besides several points whence lava may have issued. The volcanoes are most of them very entire, and the largest has a crater 455 feet deep, and about a mile in circumference. The currents of lava are, as usual, of considerable depth in the narrow defiles, but spread out into thin sheets over the plains; the upper part is scoriaceous, further down it is less porous, and at the bottom it becomes prismatic basalt, about five feet thick, resting on the subjacent Secondary rocks.

It is probable that the western part of Asia and the Peninsula of India exhibit the phenomena of recently extinct volcanic action on a scale far grander than is known in Europe, for in these countries the lava has been poured out over an area of many thousand square miles, and rests in flat tabular masses upon the country.

Volcanic rocks, like those of the Westerwald and Vogelsgebirge may be traced at intervals, both southward towards Switzerland, and eastward across the north of Bavaria into the north of Bohemia. They accompany the porphyries of the Odenwald, near Heidelberg, and the granite of the Fichtelgebirge; in some cases presenting volcanic cones, and in others only trachytic rocks. The hot springs of Carlsbad and Töplitz and the vicinity of these spots, marks the continuance of the district towards Silesia, and basaltic cones occur on the south flanks of the Erzgebirge, in Saxony, and in several places between Dresden and Freyburg. Various places in Upper Silesia, and others on the western border of Moravia, near Hungary, present rocks which can only be referred to causes resembling those now in action in volcanic districts, while in Hungary itself, on the southern flanks of the mountain chain which separates that country from Gallicia, even more striking and distinct remains are presented of ancient volcanic fire. These are chiefly of the rock called *trachyte*, which is one of the compounds formed by the association together of various silicates at a high temperature. Transylvania presents several instances of old craters and half-extinct solfataras, while Styria, North Italy, Central Italy, European Turkey, and other adjacent countries towards Asia Minor, afford connecting links with the present sources of active volcanic disturbance in South Italy and the Greek Archipelago. Several places in Asia Minor near Smyrna, and thence to the valley of the Jordan, and wide tracts in Persia, carry the evidences of volcanic agency far into Asia, while the shores of the Red Sea, and the extremity of Arabia are proofs of a similar kind in connection with the volcanic islands of the Indian Ocean.

236. In many parts of our own country and elsewhere, but especially in the Isle of Staffa and the opposite coasts of Antrim in Ireland, indications are afforded of the presence of melted rock, identical in composition with lava, and yet unconnected with any obvious volcanic appearances. Such indications have generally been referred to submarine eruptions, but as they can hardly be

Fig. 35.



View of Fingal's Cave, Isle of Staffa.

described without some account of the beds and other rocks with which they are associated, any details must be postponed to a future chapter. Beds of lava thus dissociated from true volcanoes are usually called *basalt*, but they differ much in appearance, texture, and even composition. With them, and sometimes without any other evidence to connect them with igneous agency, we not unfrequently find minerals and rocks referred to as tuff or volcanic ash, but such evidence is imperfect, and in many respects unsatisfactory.

237. We have seen that in the neighbourhood of volcanoes and in extensive districts subject to earthquake action, there are often local and temporary changes of level, consisting frequently of oscillations, and limited to small areas. Besides this, however, elevation and depression of a different and more extensive kind has been observed in many parts of the world where no vicinity of volcanoes and no distinct subterranean action can be traced, to account for such change. The coasts of the Baltic Sea and Northern Ocean, the coast line of Britain, and the shores of Greenland, have been chiefly referred to in evidence of elevation of this kind, but it will be clear, on a moment's consideration, that some peculiarly favourable circum-

stances are required that we may obtain the required proof of the fact in question. The amount of supposed change is indeed rarely more than a few feet in a century, and no measurements of the elevation of land above the sea-level so accurate as this have been made till within a very few years, owing partly to the real difficulties of measurement, and the liability to error from the imperfection of instruments, and partly to the absence of any admitted and recoverable base line. On the shores of the Baltic, however, where there are hardly any tides, where the inner line of coast is defended by a fringe of islands, and where the rocks are hard and often very near the surface, the means are presented by nature, and they have not failed to attract notice. The result is, that there appears to have been a gradual but slow upheaval, very different in different places, but sufficient, in the course of the last two or three centuries, to lay bare many rocks before sunk, to expose the foundations of buildings built on the shores at the water line, to choke up and render useless old channels between rocks, and even to lay bare some beds of marine shells. The so-called *raised beaches*, found in various parts of England at a height of from 20 to 200 feet above the present coast line, often exhibit gravel and sand with marine shells having all the peculiar features of the existing sea beach; and similar terraces, more or less distinctly marked in various places along the whole European coast line of the Atlantic, afford ample proofs that this change of level and gradual uplifting of the land has gone on for a long while. Some remarkable ledges, eaten out, as it were, from the hard and steep rocks, at certain heights on the bold cliffs of Finmark near the North Cape, seem to prove that there must have been long alternations of elevation and repose; and also that the elevations have been by no means uniform over the whole area lifted, but much more in one direction than any other, and gradually less in amount in a direction at right angles to this.*

238. South America, also, as it presents the most magnificent chain of continuous mountain ridges and the largest river systems in the world, seems to afford the most distinct and best instances of slow elevation, and the upheaval of an ocean floor into the main land of a vast continent. Mr. Darwin has shown that for a distance of at least 1200 miles from the Rio de la Plata to the Straits of Magellan on the eastern side, and for a still longer distance on the west, the coast line and the interior have been raised to a height of not less than 100 feet in the northern part, but as much as 400 feet in Patagonia. All this change has taken place within a comparatively short period, for in Valparaiso, where the effect is most considerable, modern marine deposits with human remains are seen at the height of 1300 feet above the sea.

* See the evidence on this subject collected by M. Bravais, and translated in the "Quarterly Geological Journal," vol. i. p. 534.

239. The vast tracts described in the last chapter* and presenting the work of the coral animal as an effectual barrier against the waves of the Pacific, seem to mark areas of subsidence not less extensive than those of the main land of South America exhibit elevation. The only reasonable explanation of the existence of banks of dead coral many hundred feet deeper than the extreme limit at which the coral animal which built them could have lived, is in the assumption that a gradual depression took place of the land on which they were originally based, and this also involves the former existence of a large tract of land near the Equator to the east of, and partly including the Indian Archipelago. That such depression of a large area is in other respects probable, appears from the form and distribution of the land in that part of the world, and from the fact of the elevation of large areas elsewhere.†

"That the bed of the Pacific and Indian Oceans, where atolls are frequent, must have been sinking for ages, might be inferred, says Mr. Darwin, from simply reflecting on two facts; first, that the efficient coral-building zoophytes do not flourish in the ocean at a greater depth than 120 feet; and secondly, that there are spaces occupying areas of many hundred thousand square miles, where all the islands consist of coral, and yet none of which rise to a greater height than may be accounted for by the action of the winds and waves on broken and triturated coral. Were we to take for granted that the floor of the ocean had remained stationary from the time when the coral began to grow, we should be compelled to assume that an incredible number of sub-marine mountains of vast height (for the ocean is always deep, and often unfathomable, between the different atolls) had all come to within 120 feet of the surface, and yet no one mountain had risen above water. But no sooner do we admit the theory of subsidence, than this great difficulty vanishes. However varied may have been the altitude of different islands, or the separate peaks of particular mountain chains, all may have been reduced to one uniform level by the gradual submergence of the loftiest points, and the additions made to the calcareous cappings of the less elevated summits as they subsided to great depths."‡

240. Such, then, is the evidence on which we assume that there are districts of the earth now undergoing depression on a scale not dissimilar to, nor, indeed, unconnected with that on which we recognise elevation. By observations of this kind on low islets which only retain their existence because they have been found convenient for the habitation and structures of the coral animal, we are enabled to recognise the last vestiges of lofty peaks, which once, perhaps, existed as mountain tops penetrating the region of the clouds. We thus reconstruct in imagination the land which has been submerged, and may even be induced to speculate concerning the date of the submergence, and the plants and animals that clothed the ancient continent.

Considered, however, in their extent, and in their bearing on the general argument, these various facts and probabilities with respect to disturbance of the earth's crust suggest conclusions in the highest degree important and interesting.

* See § 178.

† See a Memoir on this subject by Mr. Dana, "Silliman's Journal," vol. xlv. p. 131.

‡ Lyell's "Principles," *ante cit.* p. 760.

We have seen, for instance, that the solid framework of our globe is frequently exposed to subterranean action, obtaining relief from time to time by volcanic outbursts of melted rock and ashes thrust forth from beneath with almost inconceivable force and velocity; at other times tearing asunder the thin crust that has cooled over the boiling and restless mass beneath, producing undulations and earth-waves which embrace in their vibrations a large proportion of the surface, which carry terror with them and leave destruction behind them. We have seen, also, that besides movements of this kind, readily and immediately perceived, there are others, affecting areas no less extensive, and in a still greater and more permanent manner; modifying the form of land, producing or destroying continents and islands, and effecting changes which in their turn influence the conditions of life upon the earth.

Changes of this kind, so considerable that it is difficult fully to realise their amount, so majestic in their progress that the age of man is hardly an appreciable instant in reference to the time they occupy, so directly influencing the great physical features of the earth, that our speculations with regard to them carry us back to an early period of its existence, will at once be recognised as of the most vital importance in reference to the continuous and ancient history of our globe.

And the facts thus learnt harmonise perfectly with other phenomena of nature, for they speak of the existing condition of things as incidental and not permanent: as a part, and a very small part, of a mighty and continuous whole.

They remind us, also, that if we study nature we must everywhere, and at all times, expect modification and change. The ideas of matter and motion are thus seen to be inseparable, and no rational conclusions can be arrived at without bearing this truth constantly in mind.

And, lastly, we learn that although there is nothing permanent in the forms which matter may assume, there is still order and unity, and the most enduring permanence in the laws which govern and produce them. This is beyond doubt a conclusion of infinite value, for it connects together into one system facts and groups of facts which would otherwise be discordant, and it affords the key for the solution of innumerable difficulties and apparent discrepancies observed when we endeavour to trace out the great plan of nature.

PART II.

MINERALOGY.

CHAPTER VII.

CRYSTALLOGRAPHY, OR MINERAL SUBSTANCES AS DETERMINED BY FORM AND STRUCTURE.

241. It is the object of Mineralogy to describe the form, the internal structure, the chemical composition, the physical properties, and the uses to man of all those natural material productions which are not organic, or in other words, of those not capable of reproducing their like by any mutual action, and not modified by the influence of life. The combinations of which it treats are thus always identical under similar circumstances, and far from any modification being induced in the results in different countries, or at different times, as is the case with animals and vegetables, there can be no reason to doubt that during all time—for so long, at least, as the same laws have been in existence—similar minerals and rocks may have been repeated without variety. In all simple minerals, therefore, of which the particles have once obtained a condition of mechanical and chemical equilibrium, there seems to be no tendency to change or undergo decomposition were it not that chemical forces are constantly at work, tending to decompose and rearrange all existing combinations of matter.

242. Like all Natural History sciences in which numerous individuals have to be described in their mutual relations to one another, the classification of these, or the arrangement of like individuals in certain groups, is a most important preliminary study, since it is only by the aid of arrangement that we are enabled to remember, communicate, and apply our knowledge. In a good systematic nomenclature ideas are suggested by mere position in the system, and a knowledge of this position becomes a representative of the natural substance itself. Without such a basis, indeed, there is little

advance to be made; and thus it is requisite that certain properties should be admitted and recognised by which the different groups are naturally and readily distinguished, and these may be called the characteristics of the individual.

243. The characteristics of minerals, or the Natural History properties by which we distinguish one from another, are of very different kinds. They include colour, external form, hardness, weight, and internal structure, as the most important visible characters, while actual chemical composition affords the most valuable information when minute comparison and further investigation are needed. Besides these there are certain optical and electrical properties, and some other physical ones which are also well worthy of careful attention; and, lastly, there exist very well marked and curious relations of form, the result, probably, of chemical action, which it is necessary to consider minutely in determining the true nature of simple minerals.

244. It may seem, perhaps, that mere form is not likely to be so important a character in the determination of minerals as many others, for we are in the habit of regarding stones and minerals as almost without definite shape. In reality, however, few things in nature are so truly and neatly defined as simple minerals; and on looking a little more closely we shall find that this is the case not only externally, but also in intimate structure, so that not only are many substances found in nature having a regular shape, but these can often be cleaved or split readily in a certain way, while if broken in any other direction they exhibit ragged and uneven edges. Such bodies are technically said to exhibit *structure*, because, although the texture of the interior of other stones and minerals may be equally manifest, yet in these only does the observation of texture lead to a knowledge of the mode of formation.

245. The various natural history properties of minerals require to be understood before it is possible to have any distinct notion of Mineralogy; and in order to appreciate these properties much attention must be paid to the subject of form. It is fortunate for the student that the number of original forms is greatly limited in nature; and although the number of possible combinations of known elementary substances is almost infinite, the knowledge of form required is not so difficult as it might at first seem. We must first consider the subject as having reference to structure generally, in a mathematical sense, before proceeding to the other physical characters, such as the chemical composition, or the mutual relation of the various physical properties.

246. The regular forms assumed by minerals are well known under the name of *crystals*, and the part of mineralogy which refers to it is thence called CRYSTALLOGRAPHY, or a description of crystals. The first thing to be done, therefore, is to become familiar with

crystals, especially those met with in nature, and to learn the relation they have to one another, and to simple commensurable solids to which they can be shown to belong.

In the transition from the gaseous or fluid state to the solid, many substances assume the condition of a regular geometrical solid bounded by plane faces. Such are the forms most readily recognized as 'crystals,' and they occur, whether the solidification takes place by the separation of the solid from an aqueous solution, or by cooling from igneous fusion. The beautiful crystals occasionally found in nature, forming part of the earth's crust, and embedded in various rocks, have, doubtless, been formed under one of these conditions. In some cases, as in the sublimation of sulphur, a body proceeds at once from the gaseous state to the solid without passing through the fluid state. In others, slow cooling from a high temperature to a much lower one superinduces the same condition, without a transition from one condition of matter to another.

Each substance usually exhibits a peculiar crystalline form of its own, although occasionally the same substance crystallizes in two distinct and incompatible forms, in which case it is said to be *dimorphous.* Sometimes also two different substances are found having the same crystalline form, and they are then said to be *isomorphous.** These terms will be subsequently illustrated at greater length, and their bearing on mineralogy considered.

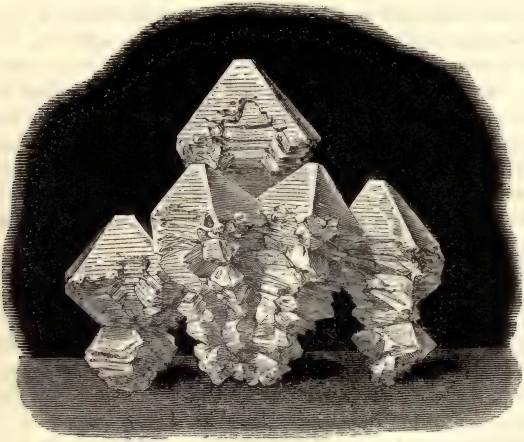
247. When several crystals of the same substance are examined we do not find amongst them an absolute geometrical identity of form. The annexed figure (36) represents a group of alum crystals, in which the actual form is confused, but where the prevalence of an arrangement of one kind of forms may be readily distinguished. Widely, however, as different crystals may seem to depart from the normal or typical form, they may usually be traced to this with more or less difficulty. Thus, in quartz crystals where the usual form is that of a six-sided prism terminated by six-sided pyramids, the sides of the pyramids are by no means always regular and alike, for they are of various sizes and in various relations to one another, and in this way are produced many irregularities; but a careful examination shows that notwithstanding apparent modifications, and in spite of all these differences, the angle between corresponding faces in crystals of the same substance is invariable. Thus the angle between two sides of the prism of quartz is invariably 120°, and the angle between the adjacent sides of the pyramid is 133° 44′, and so on.

248. Simple crystalline minerals are generally so constructed and

* *Dimorphous* from (*dis*) twice and (*morphe*) form, and *Isomorphous* from (*isos*) like, (*morphe*) form, signify respectively diversity of crystalline form in the same mineral species, and assumption of the same crystalline form by two different minerals. By *crystalline form* it is here meant to include every compatible variety belonging to a distinct system of crystallization. (See § 289—300.)

so built up of like parts, that, by proper management and a skilful hand, we can obtain an ultimate or primitive form of each crystal by splitting off parallel faces of various thickness, or by removing edges, or angles, which may have replaced faces. To understand this

Fig. 36.



Group of Alum Crystals.

fully requires a little familiarity with the nature and derivation of solid figures, and the terms employed in speaking of them.

249. The following are the more important laws with respect to this property, which is technically called *cleavage* :—

1. It is uniform in all the varieties of the same mineral.

2. It occurs parallel to the faces of a fundamental form or along the diagonals.

3. It is always the same in character parallel to similar faces of a crystal, being obtained with equal ease, and affording planes of like lustre—and conversely, it is dissimilar parallel to dissimilar planes. Thus it is the same parallel to all the faces of a cube ; but in the square prism, the cleavage parallel to the base differs from that parallel to the sides, because the base is unequal to the lateral planes. There may be an easy cleavage parallel to the base, and none distinct parallel to the sides, as in topaz ; and the reverse may be true.

4. All simple minerals do not present cleavage, or, at least, the cleavage, in many, cannot be discovered. Quartz, for example, cannot be cleaved by the knife and hammer ; but it may, sometimes, be made to exhibit the property by plunging it into cold water, while very hot.

5. Some minerals present peculiar cleavages of subordinate character, independent of the principal cleavage ; thus, calc spar has, sometimes, a cleavage parallel to the longer diagonal of its faces.

6. Cleavage extends to rock masses, where it is observed, as in slate, chiefly with reference to one set of planes. The jointed structure, in many rocks, is also a result of the same property.*

* Dana's "Manual of Mineralogy," p. 35.

250. An angle of a plane figure is well known to be formed by the inclination of two lines meeting at a point. It cannot, of itself, enclose any space, since every limited space or area requires at least three straight lines to enclose it, and must, therefore, have at least three angles.

An angle of a solid figure, on the other hand, is (see fig. 37) composed of at least three planes or faces which meet in a point, and such an angle is called *a solid angle.* If, therefore, from a solid we cut off an angle there must be a face instead, and this is called replacing a solid angle by a plane face. If there is a regular solid, or

Fig. 37.

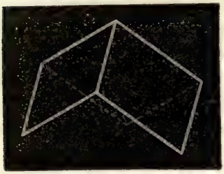


Fig. 38.

Fig. 39.

a solid formed symmetrically, by faces some of which are similar and equal (see fig. 38, 39), it is possible to alter or replace the solid angles symmetrically, and still retain symmetry, but not otherwise. In crystallography it is always supposed that changes in crystals take place symmetrically.

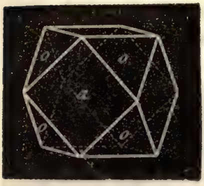
251. The symmetry here understood is strictly mathematical, and supposes constant reference to perfectly regular and exactly corresponding parts. In the case of a cube, where the sides are all equal, and the solid angles also exactly equal and placed in the same way, it would mean acting at the same time in the same way and to the same extent on all the sides together, or all the solid angles together, or all the edges together. If, however, the figure should be a prism, such as a double cube, then the four enclosing sides, the two end planes, the four edges of the sides, and the eight of the two ends would have to be considered as distinct groups, and any one set could be acted on independently of the other. Hence arise many of the peculiar modifications of form seen in crystalline solids, and the necessity of understanding what is really meant by symmetrically acting on a fundamental or derived form.

252. Besides solid angles and the plane faces which enclose them, and of which every solid body must have, at least, four, there are also *edges* formed by the inclination of each two planes towards each other, and these are also symmetrical in all regular figures (see fig. 39). If we take the simplest solid as a cube (fig. 41), there will clearly be six equal sides, or plane faces, all squares ; eight equal solid angles (each exhibiting three equal plane angles), and twelve equal edges ; and since each solid angle is made up of three plane angles, there must be twenty-four plane angles. In this case all the plane angles are right angles.

253. Now, if a crystal exist in the form of a cube and be cleaved or split to the same extent parallel to each side, we may thus repro-

duce smaller cubes; but it may also be possible to remove the solid angles; and if this is also done symmetrically, or so that each portion removed is exactly alike, we shall obtain a different solid, also regular, but derived from the cube, and at length becoming a figure like that shown in fig. 40, where the letter *a* marks the original surfaces, and *o* the new surfaces produced by the removal of the solid angles. The new surfaces will be triangles whose sides are all equal, and the old surfaces, though reduced in size and changed in position, are still squares. The figure now having six square sides has eight triangular ones besides, and is thence called the *cube-octahedron,** by which is meant a figure derived from the cube and octahedron. It has twelve solid angles, six square plane faces (*a*), eight triangular plane faces (*o*) which are derived, twenty-four edges and forty-eight plane angles. Most natural crystals are capable of being cleaved or split in some particular directions in accordance with the law of their formation; and in this way, by aid of cleavage, we may derive one solid from another, and discover the simple and fundamental form from the complicated or less simple one.

Fig. 40.



Cube-octahedron.

Crystals modified in this way can only be affected according to the following laws:—

1. All the similar parts of a crystal are similarly and simultaneously modified, or
2. Half the similar parts of a crystal, alternate in position, are modified independently of the other half.

The following terms are employed in describing the modifications of crystals.

Replacement; an edge or angle is replaced when cut off by one or more secondary planes.

Truncation; an edge or angle is truncated when the replacing plane is equally inclined to the adjacent faces.

Bevelment; an edge is beveled when replaced by two planes which are respectively inclined at equal angles to the adjacent faces. Truncation and bevelment can occur only on edges formed by the meeting of equal planes.

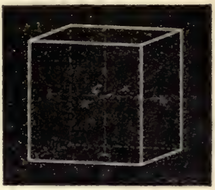
254. In describing the crystalline form of a body it is necessary to neglect accidental modifications, and consider each surface, or enclosing plane, as if it were removed or supplied in perfect symmetry. The ultimate or primitive form thus obtained may be conveniently called the *ideal crystal*, to which the actual crystal only approximates, sometimes more and sometimes less distinctly (see fig. 36). One reason why the same surfaces do not always exactly correspond in nature is in consequence of accidents of original formation or subsequent interference, the result being that the general aspect

* Crystalline forms are often described by terms borrowed from the Greek language. Thus, *octa* signifies eight, and *hedron* side; and the following, derived from the Greek numerals, and constantly used in composition, may be useful to assist the memory of the student:—*hemi*, half; *monos*, one; *tetra*, four; *penta*, five; *hexa*, six; *hepta*, seven; *octa*, eight; *deca*, ten; *dodeca*, twelve; *ikosi*, twenty. So also *gonos* signifies an angle.

of the crystal is often so different from the ideal form, that it is difficult for the beginner to recognise the one in the other. It is, however, highly important that this point should be carefully attended to, since very apparent and considerable modifications in form are produced by the unequal distance of the plane faces from the middle point of the crystal.

255. In order to obtain a starting point from which we may more closely investigate crystalline form, and the comparison of opposite and corresponding positions of detached plane faces, certain lines have been assumed in crystals under the name of *axes*, with regard to which the different plane faces exhibit a symmetrical position. The lines, for instance, drawn in fig. 41, through *c* the centre of the cube to the middle points of each side, are of this kind. All the lines thus drawn are of equal length, and each makes right angles with the other two. Everything that can be done or described with respect to the solid can be referred to these lines, and all calculations made much more conveniently with respect to them than in any other way.

Fig. 41.



The position of such lines or axes, and the relation of the parts into which they divide the crystal, is not the same in all cases; and with respect to this fundamental character six different crystalline systems have been assumed, to which the greatest attention should be paid, as they illustrate the whole subject of crystalline form.

256. 1st.—The *regular* (also called *octahedral, monometric* or *tesseral*) *system,* in which there are three similar and equal axes at right angles to one another. This system includes the cube, octahedron, dodecahedron, and a number of other well known figures.

2nd.—The *square prismatic,* or *di-metric system,* with three axes at right angles to one another, but not all equal to one another. Includes the square prism and square octahedron.

3rd.—The *hexagonal system,* in which are four axes, of which three are similar and in one plane, intersecting one another at an angle of 60°, while the fourth axis is dissimilar and at right angles to the plane. Includes the rhombohedron and hexagonal prism.

4th.—The *rhombic, prismatic* or *trimetric system,* with three axes at right angles to one another, but all dissimilar. Includes the right rhombic prism, right rectangular prism, and rhombic octahedron.

5th.—The *monoclinic,* or *oblique prismatic system,* having three dissimilar axes, two of them not at right angles to one another, but the third at right angles to both of them, and to the plane in which they are. Includes the right rhomboidal prism, and oblique rhombic prism.

6th.—The *triclinic*, or *doubly oblique prismatic system*, in which the axes are dissimilar, and no one is at right angles to the others. Includes the oblique rhomboidal prism.

257. The relative importance of each system will be best understood by the following table of 351 minerals referred to crystalline systems in one of the latest works on Mineralogy (Nicol's "Mineralogy"). Out of the whole number of species there described (506), 36 are mentioned as amorphous, 64 massive, and 21 compact. Several are doubtful, some dimorphous, and some isomorphous.

1st	Regular system	67
2nd	Square prismatic system	33
3rd	Hexagonal system	66
4th	Rhombic system	107
5th	Monoclinic system	64
6th	Triclinic system	14
		351

It should be mentioned that the rhombohedral forms of the third system are sometimes distinguished from the hexagonal. Of the number of species in the third system 33 belong to the former and the same number to the latter division.

The First, or Regular System.

258. It is usual to consider the regular octahedron as the fundamental or ideal, as it is the simplest form, of the regular system. It is a solid enclosed within eight similar and equal triangles. The solid angles, the edges, and the angles which the plane faces make with each other are all equal, the latter being 109° 28′. The axes are the lines joining opposite angles, and are all equal, and at right angles to one another. In the figure (42) the angles are marked by the letter A, the edges by D, and the plane faces by O. The whole may be regarded as a double pyramid perfectly symmetrical in every respect.

Fig. 42.

The regular octahedron is a form which many substances, both simple minerals and the results of artificial manipulation, commonly assume. Among them we may mention magnetic iron, and perfect crystals of alum.

259. Various modifications of the octahedral form are produced by removing portions of the solid by planes parallel to one or more of the different plane faces, edges, or solid angles. In this way are obtained the common crystals of alum, some of the salts of lead, and many other minerals. The following are simple secondary forms derived from the octahedron.

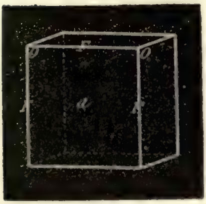
1.—The *cube* or *hexahedron* as seen in fig. 43. In this the solid angles (A) of the octahedron (fig. 42) are supposed to have been replaced (or cut off) by plane faces (*a*), and the plane faces (*o*) by

solid angles (O); the edges (D) disappear, and instead of them other edges (F), are formed at right angles to them. Each of the solid angles in this case has been removed, as far as the central points of each of the triangular plane faces.

2.—The *dodecahedron* (fig. 44) is formed by twelve *rhombic* * faces, the angles being of two kinds. In this figure the edges (D) of the octahedron have been replaced by planes (*d*), the plane faces (*o*) by solid angles (O), and new edges (G) are introduced at the intersection of the planes (*d*). The original angular points of the octahedron (A) are retained, but the planes of which the angle is made up are altered.

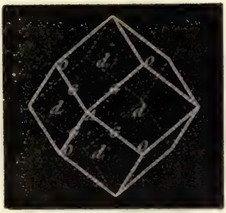
3.—The *tetrakis-hexahedron,* or pyramidal hexagon (fig. 45), is a solid of twenty-four faces consisting of a cube surmounted on each plane face by low pyramids. It is hardly necessary to describe the

Fig. 43.



Cube.

Fig. 44.



Dodecahedron.

Fig. 45.

Tetrakis-hexahedron.

way in which either this, or the pentagonal dodecahedron (fig. 46) is derived, further than by mentioning the introduction of faces marked $d/_2$, which will readily be seen to have reference to the faces *d*, derived in the dodecahedron from the edges of the octahedron marked D. There is also the *ikosi-tetrahedron,* and some other forms rarely met with, and which need not here be noticed.

Fig. 46.

Pentagonal dodecahedron.

260. Besides the ordinary modifications of a crystal by the treatment of each part symmetrically, there are also to be considered the half modifications already alluded to. Forms of this kind are called *hemi-hedral,* or half-sided; and one of the simplest is obtained from the octahedron, by continuing alternate faces till the intermediate faces disappear. According to the faces made to disappear, the result will assume one of the forms represented in the diagrams

* A rhomb is a plane figure, of which the opposite sides and angles are equal, but the angles are not right angles.

figs. 47, 48, which are perfectly equal, but differ in position. The figure is called the *tetrahedron*, or four-sided. The polygonal dodecahedron (fig. 44), may be derived in the same way and may be regarded as a hemihedral form easily derived from the tetrakis-hexahedron, which is a twenty-four-sided figure.

Fig. 47.

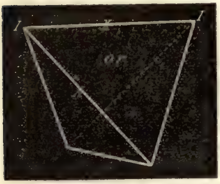
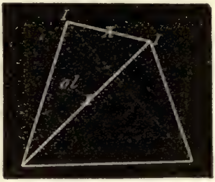


Fig. 48.



Views of the tetrahedron.

261. We come now to the cases of combination belonging to the first system. In the first of these (fig. 49), the form of the octahedron prevails, and in the next (fig. 50) the cube form prevails. Both are combinations of the cube with the octahedron. When the two forms are equally developed the resultant figure is the *cube-octahedron* already referred to (fig. 40).

Fig. 49.

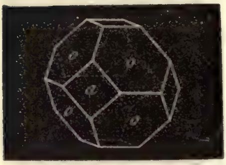
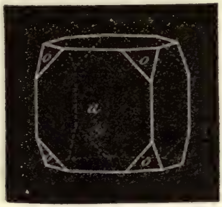


Fig 50.



The next figure (51) represents a combination of the dodecahedron and the octahedron. In this figure the faces (*o*) of the octahedron predominate, and the form obtained by the modification is very peculiar. Fig. 52 is a combination of the cube with the dodecahedron, and fig. 53, that of the tetrahedron with the cube. These are the principal combinations met with in nature, but we add the figure of a combination of three forms (see fig. 54), viz., the cube (*a*) (which dominates) with the octahedron (*o*), and the dodecahedron (*d*).

Fig. 52.

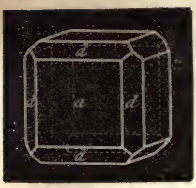
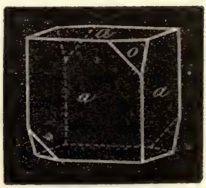


Fig. 51.

Fig. 53.



262. Among the forms of crystalline bodies most important to be known, and belonging to the first or regular system, are the following. The names of some of the minerals frequently met with of the different forms, are added as instances :—

Octahedron (*o*) :—Spinelle, Magnetic iron ore. (fig 42.)

Hexahedron or cube (*a*):—Fluor spar, Rock-salt. (fig. 43.)

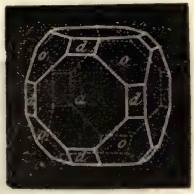
Dodecahedron (*d*) :—Garnet, Hauyne. (fig. 44.)

First ikositetrahedron :—Leucite, Garnet, Analcime.

Hemi-octahedron (tetrahedron) :—Grey copper, Blende. (figs 47, 48.)

First tetrakis-hexahedron :—Gold, Copper. (fig. 45.)

Fig. 54.



It will be easily understood that, provided the system is the same, a mineral may present itself in various forms without being dimorphous. Thus Garnet is sometimes dodecahedral and sometimes ikositetrahedral.

263. The principal abundant or useful minerals crystallizing in the first system are the following :— Alum, Analcime, Blende, Boracite, Native copper, Chromate of iron, Diamond, Fluor spar, Galena, Garnet, Gold, Grey copper, Horn silver, Native iron, Iron pyrites, Leucite, Magnetic iron ore, Native mercury, Red oxide of copper, Rock salt, Sal ammoniac, Native silver, Smaltine, Spinelle.

The Second, or Square Prismatic System.

264. The fundamental form of this system is the square octahedron, a figure which differs from the regular octahedron in the vertical axis being either longer or shorter than the horizontal axes. The adjacent figure (55) represents the solid in the latter case. The

Fig. 55.

Fig. 56.

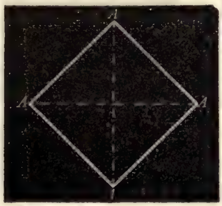
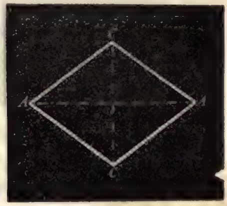


Fig. 57.



vertical axis in this system has no proportional relation to the others ; in Zircon, for instance, the relation is as 0·64 to 1, and it varies with the mineral species.

The eight sides of the square octahedron are not equilateral triangles, but are all equal to each other. The section through the lateral angles (A) is a rectangle, and is called the base (see fig. 56), while the section through the vertical angles is a rhomb (fig. 57). There are thus two dimensions of solid angles, the vertical and horizontal ; the latter made up of four similar and equal angles, and the former of four angles, not all similar and equal.

265. In all the octahedrons of the second system the principal axis joins the two vertical angles, but the secondary axes may have

either the position seen in fig. 58, joining the opposite angles of the base, or that of fig. 59, uniting the middle points of opposite sides. The two kinds of figures thus formed are called respectively the direct and the inverse, or octahedrons of the first and second class.

Fig. 58.

Fig. 59.

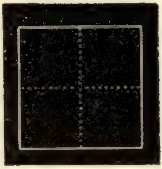


Fig. 60.

266. The combinations of the second system include, *first*, that of the direct and inverse octahedrons with each other, as shown in fig. 60, which has the edges (D) and the angle (C) replaced by sides *d* and *c*.

Fig. 61.

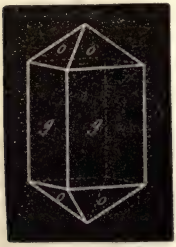


Fig. 63.

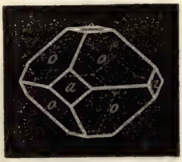
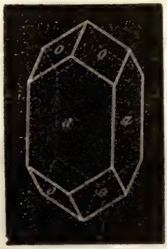


Fig. 62.



In fig. 61 is a combination of the primitive octahedron with the right prism of the same class. We have next (fig. 62) the combination of the acute octahedron with the right prism of the second class, the latter being the principal form; and, thirdly (fig. 63), the obtuse or primitive octahedron, with the prism of the second class, the octahedron dominating.

Fig. 64.

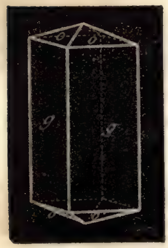
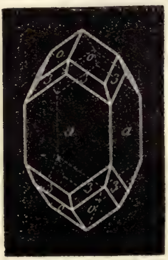


Fig. 65.



When the edges of the long square octahedron are truncated the resultant figure becomes a prism; and this may either remain a parallelopiped or be terminated with a low pyramid. Thus the combination of the primitive octahedron with the right prism of the same class gives the figure represented in 64.

Lastly, fig. 65 represents the primitive (obtuse) octahedron combined with the acute octahedron of the same class and the right prism of the second class. The prism here dominates.

267. The hemihedral forms of the second system correspond with those of the first, and the hemi-octahedron is the most important. Crystals of this kind are derived from the square octahedron of both classes, just as the tetrahedron is derived from the octahedron, the faces being isosceles triangles, the edges of two kinds, and the angles unequal. Copper pyrites occurs in this hemihedral form.

268. The following are the principal minerals of this system, viz.—Apophyllite, Copper pyrites, Idocrase, Rutile, Scapolite, Tin ore, and Zircon.

The Third, or Hexagonal System.

269. The forms which belong to this system have four axes, three of which are equal and in one plane, making angles of 60° with each other, and the other axis is at right angles to the plane in which these are. The vertical axis is taken as the principal axis. No relation exists between the length of the principal and secondary axes. The diagram, fig. 66, is the principal simple form, and consists of two hexagonal pyramids on a common hexagonal base. The faces are isosceles triangles. The edges are of two kinds, twelve terminal (D), and six lateral (G). The solid angles are also of two kinds, two terminal or vertical (C), of six plane faces, and six horizontal or lateral (A), of four. This figure is the *hexagonal dodecahedron.*

Fig. 66.

There are two classes of dodecahedrons dependent on the disposition of the secondary axes with respect to the base. In the first class, the axis join the angles of the base as in fig. 67, and in the second class they join the middle of the opposite sides, as in fig. 68. Hence result some combinations and derived forms.

Fig. 68.

Fig. 67.

Fig. 69.

270. The *rhombohedron,* or *hemi-dodecahedron,* is a form derived from the dodecahedron, and admits of two varieties, the one repre-

sented in figure 69, and another having the same relation to this as the second tetrahedron has to the first. These are the hemihedral forms of the third system, and they are very important, as the number of minerals crystallizing in this manner is as large as that in which the forms are not hemihedral.

271. The combinations in this system are varied, and have considerable interest, but it is not necessary to describe many of them. In fig. 70 is that of the primitive dodecahedron with the first derived

Fig. 70

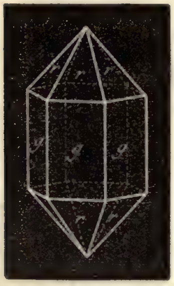
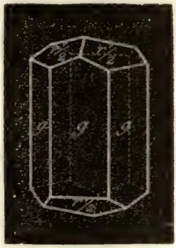


Fig. 72.

Fig. 71.



prism. It is the most usual form of Quartz. The next figure (fig. 71) represents the prism combined with the principal rhombohedron. We sometimes find a hexagonal prism (72) terminated by plane faces —a combination of the prism and the terminal faces.

272. The following are the principal minerals that crystallize in this system in the complete (*holo-hedral*) form. Apatite, Chlorite, Copper-nickel, Emerald, Graphite, Uni-axal or Magnesia mica, Pyromorphite, Quartz, and Red oxide of zinc. The following are usually rhombohedral (*hemi-hedral*) forms: Native antimony, Native arsenic, Calamine, Calc spar, Chabasite, Cinnabar, Corundum, Dolomite, Manganese spar, Spathic iron, Specular iron, and Tourmaline.

The Fourth, or Rhombic System.

273. The characteristic of this system is, that although the three axes of the octahedron, which is its fundamental form, are at right angles to one another, as in the regular and square prismatic systems, no two of them are equal to each other. The relation of magnitude also is different for different bodies, and no one of the axes can be considered the principal one; although, for the sake of convenience, the one most commonly presented as principal in the ordinary form of any particular crystal is sometimes so designated.

In this system the common base of the octahedrons is a rhomb and not a square; it has therefore two obtuse and two acute angles, and its diagonals are unequal.

It hence results, that of the six angles of the figure there are only two and two alike, so that they can be symmetrically modified only

to this extent. The only simple form is the right octahedron with a rhombic base, fig. 73, of which figs. 74, 75 are the sections made by planes through the terminal edges. Fig. 76 represents the base.

Fig. 73.

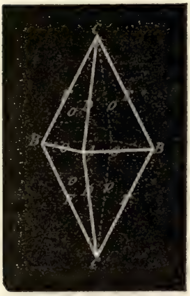


Fig. 76.

Fig 74.

Fig. 75.

274. The compound forms of this system are several. In fig. 77 is a combination of two of the octahedrons with a prism and the terminal face. Fig. 78 is the principal octahedron combined with two vertical prisms; fig. 79, a combination of horizontal prisms; and

Fig. 80.

Fig. 77.

Fig. 78.

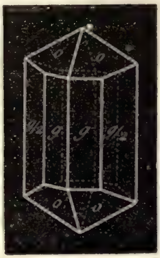


Fig. 79.

Fig. 81.

fig. 80, a combination of the vertical prism with the terminal face. Lastly, we have, as in fig. 81, combination of the principal octahedron with the lateral faces *a* and *b*.

275. Hemi-hedral forms are presented amongst the crystals referred to the fourth system; but they are much more rare in it than in the others. Sulphate of magnesia presents a tetrahedron of this nature, and in Manganite there is a combination in which it appears. There are no hemi-hedral forms of the fifth or sixth systems found in nature.

276. A very large number of minerals are referred to this system, which appears to admit of innumerable variations and modifications, resembling each other and often approximating to the forms of the regular and square prismatic systems. The following may be regarded as the most interesting and best known species,—Andalusite,

Anhydrite, Arragonite, Celestine, Sulphuret of antimony, Harmotome, Heavy spar, Brown hæmatite, Iolite, Jenite, Manganite, Mesotype, Mispickel, Nitre, Olivine, Orpiment, Prehnite, Pyrolusite, Ruby silver, Staurotide, Stilbite, Strontianite, Sulphur, Talc, Topaz, Wavellite, Witherite.

5th. *Monoclinic or Oblique Prismatic System.*

277. In this system there are three unequal axes, one at right angles to the plane in which are the two others, which latter, however, are not at right angles to one another in that plane.

Fig. 82.

The annexed figure (82) is an octahedron of the monoclinic system. It differs essentially from the octahedrons already described, not being enclosed by eight equal triangles, but by scalene triangles of two kinds. It is not met with in nature in its simpler forms, being obtained only in combination. The section obtained through the terminal edges is represented in fig. 83, and is a parallelogram. The section through the lateral edges, fig. 84, is a rhomb, and forms the base.

Fig. 83.

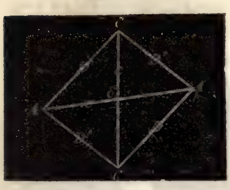


Fig. 84.

In figure 82 the four edges in each of the two planes in which are two axes not at right angles to one another, are similar and equal: of the other edges those opposite one another are similar and equal.

The four surfaces cut off by similar planes at either of the sets of equal edges form rhombic prisms, of which the edges are in each case parallel to one of the axes. These may be called oblique rhombic prisms; and in all crystals of this system an oblique rhombic prism may be considered as the prevailing form, which may be so placed that the edges are in a horizontal plane.

The octahedrons of this group may be much varied in crystals of the same mineral species, according to the length of their axes. The combinations vary also greatly; but though not a true simple form, one condition of the solid requires to be assumed as the primitive form, while the others, having relations to this, must be considered as derived.

278. The oblique octahedrons are figures of which the faces are inclined at once to each of the three axes; but there are two other groups of Monoclinic crystals, those, namely, of which the faces are inclined towards two axes being parallel to the third, and those in which the faces are inclined towards one axis, and parallel to two

others. Of these the former are four-sided prisms, which may be divided into three principal classes, viz. Four-sided prisms whose faces are parallel to the principal axis, and those whose faces are parallel to the second or third axis respectively. Some of the crystals of Gypsum (fig. 86), and a combination met with in Mesotype, are examples of the first case, and fig. 87 (a form of Pyroxene) represents the second. They are frequent and characteristic combinations.

In the annexed diagrams, fig. 85, represents a combination of the complete principal octahedron with the principal vertical prism and the terminal faces. The next

Fig. 85.

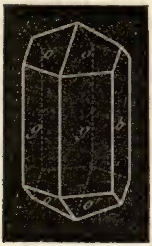


Fig. 86.

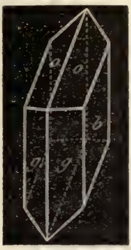


Fig. 87.

diagram, fig. 86, is a combination of the oblique anterior prism of the principal octahedron with its vertical prism and the terminal face. Fig. 87 is a combination of the oblique posterior prism of the principal octahedron of Pyroxene with its terminal oblique posterior face, its vertical prism, and the first and second lateral faces.

279. The following are the most interesting of the minerals referred to the Monoclinic system, viz.: — Augite, Crocoisite, Cyanite, Epidote, Felspar, Gypsum, Hornblende, Hypersthene, Malachite, Mica, Realgar, Sphene, Tabular spar, Talc, Vivianite, Wolfram.

6th. *Triclinic, or Doubly Oblique Prismatic System.*

280. In this system all the three axes are unequal, and neither

Fig. 90.

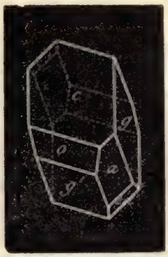


Fig. 88.

Fig. 89.

of them is at right angles to two others. The octahedron of this system (fig. 88) never appears in its complete state. It is formed of eight sides, of which only the pair parallel to one another are equal

and similar, so that each pair of such sides may undergo modification differently; and this is the case also with the edges and angles.

The oblique rhombic prism of the former system corresponds with the oblique prism of fig. 89; but the latter figure has, it will be seen, only the opposite and parallel faces, angles, and edges equal and similar. The simple form (fig. 89) is the ideal or fundamental form of Sulphate of copper.

281. The possible modifications of form of this system are numerous, and highly complicated, but the forms actually presented in nature are very few, and it includes but a small number of minerals. One of the most simple forms is represented in a diagram (fig. 90). It is a crystal of Axinite, and is a combination of the left face of the principal octahedron with parts of the vertical prism and several faces.

282. The whole number of crystalline minerals referred to this system is but fourteen, and of these Albite, Axinite, and Labradorite are the only ones of any interest.

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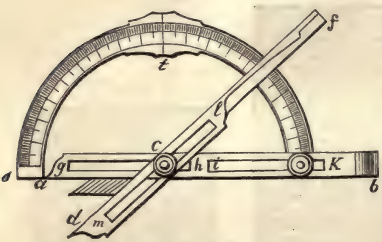
283. The ultimate forms of crystals, and the system to which they must be referred, depending thus entirely on the angles which one side makes with another, it becomes of the greatest consequence to be able to measure and determine these angles accurately. As we have already shown, the system may be determined theoretically by replacing the missing angles, edges, or sides; but since the change of form in a true crystal is always symmetrical, and the natural faces, which may easily be determined, are all inclined at the true angle towards each other, the measurement of this angle is a mechanical operation, requiring some care and some knowledge of Crystallography. Instruments have been contrived for the purpose, under the name of *Goniometers* (*gonos*, an angle; *meter*, measure).

284. The common goniometer (fig. 91) consists of a semicircular arc, divided into 180 degrees, and terminated by a diameter, *a b*.

Fig. 91.



Common Goniometer.

It is provided with two arms, one of which (*g* K) is capable of a sliding motion in the direction of the diameter, along which it is placed, and the other arm (*d f*) turns on the centre of the arc. Each of these arms is partially slit, to allow of the parts on one side of the centre being shortened, and thus admit of a more accurate measurement of small crystals. The faces of a crystal whose angle of inclination is to be measured, are applied between these arms when opened just sufficiently to admit them; and when the arms

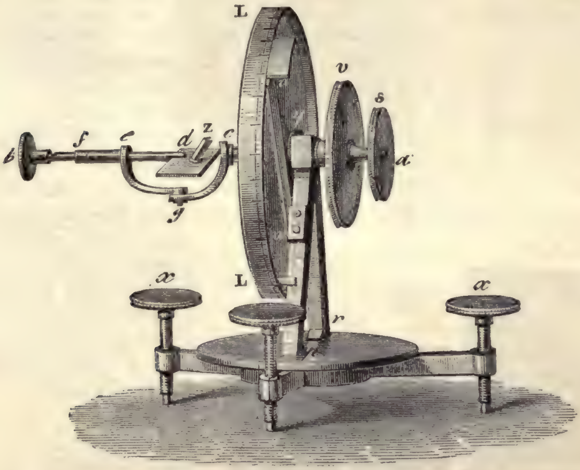
are found, on close examination, to touch them both along the whole length, the number of degrees may be read off on the edge of the revolving arm.

In the absence of such an instrument, results, often sufficiently near, may be obtained by making a pair of extempore arms of card, and laying off the angle when measured on a piece of paper, when it may be determined either by a scale or any graduated arc. It is seldom that by the common goniometer we can measure within a quarter of a degree of truth, and this is rarely sufficient to have any important scientific value.

285. The reflecting goniometer is a far more accurate instrument than the former, and may be applied with as much convenience to very minute crystals, which are generally more perfect, as to larger ones which alone can be measured by the former instrument. It is found that surfaces of $\frac{1}{100}$th part of an inch are sufficiently large for the purpose of determination by it.

The instrument (fig. 92) consists of a movable circle, LL, having a rim graduated to half degrees, and a fixed vernier scale for more

Fig. 92.



Wollaston's reflecting Goniometer.

minute measurements. A hollow main axis, *a b*, passes through the centre of the circle, and another, *a c*, passes through it, turned by the handle *s*, by which the crystal only is moved, in order to complete its adjustment. The crystal, *z*, being then conveniently fixed, by means of a piece of wax or in any other way, upon the extremity of the smaller axis (and it is necessary to be so fixed that a line

drawn on the face to be examined is parallel to the main axis) the circle is set with the mark of 180° opposite the zero point of the vernier, and a horizontal line, previously assumed as a mark, is observed by reflection from the face of the crystal to coincide with another corresponding mark, the eye being brought quite close to the crystal and almost in contact with it. A bar of a window-frame may be selected as one mark, and a horizontal line on a slate as another, and the main axis is then turned until the same line is seen reflected in the next face of the crystal into the same place. The angle between the faces may then be read off by the assistance of the vernier. The circle is placed vertically by the aid of the screws *x*, and the support *p q r*, and is moved by the handle *v*.

It is not difficult to understand the optical principle on which this instrument is constructed. If the eye observes an object by reflection from the plane surface of a crystal, and the crystal be turned round until another face represents the same object in the same spot, the crystal must have been turned through an angle equal to the difference between the angle of the two faces, and the angle of the crystal can be thus obtained.

This reflective goniometer was invented by Dr. Wollaston. It is a convenient and elegant instrument, admitting of very great accuracy of measurement, and not difficult to manage with a little practice. Other reflecting goniometers have been employed by Mitscherlich, Babinet, Adelmann, and others, chiefly for purposes of very minute observation in particular cases, or where the ordinary instrument fails.

286. We have been considering in the preceding pages crystals whose form is theoretically perfect; but it is very rare that such perfection is found in specimens of minerals presented for observation, and if it does occur, the size is generally extremely minute. Many faces in the crystals commonly met with are deformed, imperfect, broken, rudimentary, or altogether wanting, and the very grouping together of a multitude of individuals prevents any one of them from retaining its normal condition. Thus, for example, the form of quartz crystals usually approximated is the hexagonal prism terminated by two hexagonal pyramids, as in fig. 93, but the shape commonly found is often extremely different. In the case of carbonate of lime again, the usual normal form is the rhombohedron (fig. 94), the angle being 105° 5′; but the cleavage being very perfect in three directions parallel to the faces of the solid, a great variety of other rhombohedrons may be obtained, more or less flattened.

Fig 93.

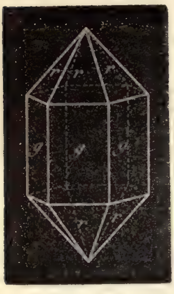
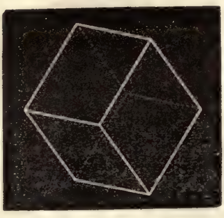


Fig. 94.



287. In their primitive forms crystals never present re-entering angles, but such appearances are not unfrequent in cases where two or more crystals grow as it were out of one base. Sometimes there is a certain degree of symmetry in the way in which individuals of a group collect themselves together, as in the crystals represented in fig. 95 (the form usually assumed by the mineral called *Staurotide*), and usually "twin crystals," as such cases are sometimes called, exhibit distinct marks of their origin. The form represented in fig. 96 is another example of complicated form, often presented by gypsum. It may be easily derived from the more simple form in fig. 97, already described (§ 278,) by cutting this latter into two parts by the plane *o m n p q r*, and making one half perform half a revolution with respect to the other. Such an arrangement is

Fig. 96.

Fig. 95.

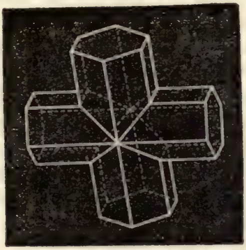


Fig. 97.

sometimes called hemitropy, and the crystal, as in fig. 96, is called a *hemitrope*. Twin crystals are also called 'macles.'

288. Crystals are occasionally found with curved faces, an accident of structure more common in some minerals than others, and not unfrequent in the Diamond. Spathic iron and Pearl spar, in like manner, present curved rhombohedrons; and certain minerals, as Alabaster and Carbonate of lime, very frequently exhibit curved crystalline forms even more curious and distinct. Other minerals run into greatly elongated and needle-shaped crystals, and are thence called *acicular*. Ice, when crystallized, often assumes very strange and sometimes extremely beautiful forms, seen both in the snow-flakes that fall through the atmosphere, and in the rime or hoar-frost that forms on windows during cold weather. The rate of crystallization very greatly influences the result, and for the elaboration of large groups time seems absolutely required. Any interruption in the process of crystallization is probably always marked in the crystal that results, and the mode of growth is laid bare when these interruptions have been regular. Crystals of quartz often show a gradual accretion of this kind.

289. Crystalline form is not absolutely to be depended on in the determination of minerals, since there are cases in which the same mineral presents itself under more than one form, the forms being incompatible or referable to different crystalline systems, while, occasionally, different minerals appear in the same or very nearly the same form. The former case is denominated *dimorphism*, or *polymorphism*, according as the number of different forms presented is two or more, and the latter is *isomorphism*. In a similar way, when minerals crystallize in nearly the same form, they are said to be *plesiomorphs*. False or imitative forms of crystals are sometimes met with, and are called *pseudomorphs*, while even the true and determinable forms are rarely complete, and exhibit numerous complications and irregularities. Of these conditions and the chemical principles involved, isomorphism is the most interesting, and will demand the most careful attention. Whatever also may be the true form of a mineral, it is, as we have seen, generally complicated by position and circumstances, thus adding not a little to the other difficulties of accurately determining mineral species. Certain substances appear especially liable to anomalous varieties of form connected with their mode of accretion; and others, although to a certain extent regular, exhibit a singular want of symmetry in some particular directions. Hemihedral forms, already alluded to, belong to this group, and certain crystals in which a very large quantity of some foreign substance or impurity is present, are also of the same kind. The crystals of Fontainbleau sandstone are examples in point. They consist of about one third part carbonate of lime, and the rest sand, and appear in rhombohedrons.

290. The following are examples of minerals frequently presented in an unsymmetrical form, viz.: *Iron pyrites* (cube), *Grey cobalt* (cube), *Grey copper* (tetrahedron), *Sulphuret of zinc* (tetrahedron), *Boracite* (cube), *Arseniate of iron* (cube), *Copper pyrites* (prism with square base), *Quartz* (rhombohedron), *Tourmaline* (rhombohedron), *Phosphate of lime* (regular prism with six faces), *Silicate of zinc* (right rhombic prism). We have named in each case the proper or symmetrical form, from which the unsymmetrical crystals are derived.

291. *Dimorphism* (from *dis*, twice, and *morphe*, form) was first observed in the case of Carbonate of lime, which in addition to the usual type of crystallization, seen in Calc spar, is presented also in Arragonite, in a totally distinct and incompatible form; but since this fact was determined many other similar examples have been found, and they appear to have reference to the existence of peculiar conditions of solidification. The following list includes all substances at present recognised as dimorphous, viz., Sulphur, Carbon, Oxide of titanium, Specular iron ore, Iron pyrites, Carbonate of lime, Carbonate of iron, Carbonate of lead, Arsenious acid, Sulphate of magnesia, Sulphate of zinc, Seleniate of zinc, Seleniate of nickel, and Chromate of lead, some of the latter salts passing from one crystal-

line system to another by the application of heat. Other substances have been described as presenting themselves in more than one system of crystallisation, but there is some doubt concerning them. Others again are trimorphous, or polymorphous, presenting themselves in more than two forms, and of these, Sulphate of nickel is an example. The fact of the same body existing in more than one usual condition, and having different physical characteristics, has been called by Berzelius *allotropy* (*allotropos*, of a different nature), and includes polymorphism, which relates only to crystalline form. Carbon is a good example of this condition, as it crystallises perfectly in the Diamond, imperfectly in Graphite, and is amorphous, but quite distinct, in Anthracite and Coal.

292. *Isomorphism* (*isos*, the same, *morphe*, form), a converse phenomenon to that of allotropy, is not unfrequently found to occur in crystalline minerals, and is far more important than it, as indicating natural relations between elements not otherwise resembling each other in their properties. By it is meant a close resemblance or actual identity of crystalline form in minerals, when one element, or proximate element, is replaced by some other. It is not easy at present to say exactly how far the general principle of isomorphism is accurately true ; but as an example of its action in well known minerals it may be sufficient to give the following measurements of the angle of the rhombohedron, into which the following minerals (all carbonates) crystallize :

Calc spar (carbonate of lime) 105° 8′
Diallogite (carbonate of manganese) 106° 51′—107°
Spathic iron (carbonate of iron) 107°
Dolomite (carbonate of lime and magnesia) 107° 25′
Calamine (carbonate of zinc), 107° 40′

293. Although, according to the most general view of the nature of isomorphism, there is no limit to the replacement that can take place in different bodies, still there are in fact such widely different degrees according to which bodies are isomorphous, that tables of these degrees afford very important information ; we quote therefore from Graham's Chemistry the following list of known isomorphous groups :

1. Sulphur, Selenium, Tellurium.
2. Magnesium, Calcium, Manganese, Iron, Cobalt, Nickel, Zinc, Cadmium, Copper Chromium, Aluminum, Glucinum, Vanadium, Zirconium.
3. Barium, Strontium, Lead.
4. Tin, Titanium.
5. Platinum, Iridium, Osmium.
6. Tungsten, Molybdenum, Tantalum.

(*And with two atoms of the preceding elements.*)

7. Sodium, Silver, Gold, Potassium.
8. Chlorine, Iodine, Bromine, Fluorine.
9. Phosphorus, Arsenic, Antimony, Bismuth.

In addition to the above isomorphous elements it may be well to append here a short list of remarkable isomorphous compounds:—

10. Alumina, Peroxide of iron, Peroxide of manganese.
11. Lime, Magnesia, Protoxide of iron, Protoxide of manganese, Protoxide of zinc.
12. Baryta, Strontia, Oxide of lead.
13. Phosphoric acid, Arsenic acid.

294. A peculiar kind of isomorphism has been noticed, which appears not unlikely to have important influence in the mineral kingdom, and which consists in the substitution of water for other substances, without change of form being induced. By the analysis of a great number of minerals it appears that one atom of magnesia, protoxide of iron or protoxide of manganese, and probably also of oxide of zinc, protoxide of nickel and protoxide of cobalt, may be replaced by three atoms of water; and one atom of oxide of copper by two atoms of water, without change of crystalline form. This is called *polymeric isomorphism* * (*polys*, many, *meros*, a part). The water in these cases is a proximate element.

295. *Pseudomorphism* (*pseudos*, false, *morphe*, form), or the occurrence of a mineral in a form not its own, and not obtained by the regular process of crystallization, occurs in various minerals, and is chiefly owing to external conditions which have limited the direction and extent of the development of the mineral. Thus crystals of quartz form in, and adapt themselves to, the cavity left by crystals of fluor spar which have been removed; and other similar instances have been from time to time observed, some well known and striking examples of which are subjoined.

296. *Specular iron*, properly rhombohedral, has been observed in octahedrons having the form of *Magnetic iron ore*, from which it has been no doubt derived. Crystals of *Carbonate of lead* are changed into *Minium*, or oxide of lead; *Minium* into *Galena*; *Witherite*, or carbonate of barytes into *Sulphate of barytes*, or heavy spar; *Wolfram*, or tungstate of iron, into *Tungstate of lime*, &c. So, also, but less easily explained, we find *Prehnite* imitative of *Analcime* and *Laumontite*; *Steatite* of *Quartz*, *Calc spar*, *Spinelle* and *Hornblende*; *Quartz* of *Calc spar*.

297. Pseudomorphous crystals are generally distinguished by having a different structure and cleavage from that of the mineral imitated in form, their angles are generally rounded, their surfaces dull, their texture is more or less granular, and their hardness different. This phenomenon may be due, *first*, to a change of composition by aqueous or some other agency, without the original crystal losing its form; *secondly*, by the actual, but gradual, and atomic removal of one mineral and replacement by another; *thirdly*, by simple infiltration into the cavity left by a decomposed crystal; and, *fourthly*, by the incrustation of one mineral upon another, by which process we first have the form of the original crystal repeated in that of the incrusting one, and then perhaps, by the subsequent removal of the first hollow, as well as pseudomorphous crystals of the second.

* First discovered by Scheerer, and referred to in Gmelin's "Hand-book of Chemistry." English translation, (published by the Cavendish Society), vol. i. p. 93.

298. The process of fossilization or petrifaction, by which organic bodies become changed into stone, and capable of indefinite preservation in the earth, is of this kind. It appears in the most perfect cases to be a substitution, particle by particle, of some permanent mineral substance, as quartz, carbonate of lime, sulphate of lime, or others, for each particle of the original organic compound. In the case of wood and the soft parts of animals the actual cellular tissue is replaced, and though in other examples the interstices between adjacent particles may only be filled up so to form a cast of the original, yet is this cast so true a representative of the most minute organization as to retain every point of structure, and endure the most careful examination under the best microscopes, without yielding any evidence as to the nature of the change or substitution that has been made.

299. Although when definite form and structure are observable in minerals, there can be no question as to the advantage, and even necessity, of referring to it as a means of determining species, still there remain a vast multitude of substances which have definite and most important properties, but no distinct crystalline form or structure, and which therefore, in technical language, are called *amorphous* (*a*, privative, and *morphe*, form). Some bodies assume the crystalline and amorphous form almost indifferently, and according to the circumstances of their passage into the solid state; some are more inclined to assume the one form, and some the other, while other again are rarely or never found in the crystalline state. Thus quartz occurs both amorphous and crystalline in great abundance everywhere, and is chiefly crystalline in mountain districts. Carbon occurs amorphous in anthracite and coal, and crystallized in the diamond and graphite. Carbonate of lime is amorphous in common limestone, semi-crystalline in marble, crystalline in calc spar; and so also with a vast variety of other substances. There are two means by which the nature of amorphous bodies may be determined, one mechanical, and involving a consideration of the physical properties of the substance; the other chemical, and requiring an analysis of the contents, and a determination of the proportions of each. We proceed in the next chapter to consider these, as affording the best methods for determining mineral species.

300. There is yet another condition to be noticed before concluding this part of the subject—it is a difference in the properties of compound bodies, probably arising from the different grouping of the simple atoms which make up a compound atom. Thus, when two or more compounds exhibit different physical and chemical relations, but are found to possess the same composition, they are called *isomeric* (*isos*, equal; *meros*, a part). Most of such instances occur in organic and not in inorganic chemistry, and therefore, it is not necessary here to refer to them more in detail. True isomeric conditions are at present recognised in the mineral kingdom with regard to phosphoric acid, tellurous and telluric acid, peroxide of tin and tartaric acid.

CHAPTER VIII.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF SIMPLE MINERALS.

301. The characteristics of simple minerals, including those that are amorphous, are, 1st. Conditions of structure or texture; 2nd. Optical peculiarities; 3rd. Phosphorescence; 4th. Electricity and Magnetism; 5th. Odour; 6th. Taste; 7th. Hardness; 8th. Specific Gravity; and 9th. Chemical Composition. Of these the first eight are generally described as physical, and are determined at once by the senses or by mechanical agency. The last, or chemical structure, requires the assistance of chemical action, and involves a certain extent of decomposition to determine it.

302. The conditions of structure of minerals are seen in their *texture, state of aggregation,* and *fracture.* The former is either columnar, lamellar, or granular, and the different kinds of each are thus distinguished :—

1. *Columnar texture* is that which is made up of minute fibres or prisms, closely compacted together. It is common in the seams of rocks, and sometimes in incrustations. It may be of the following kinds :—

Fibrous, or with delicate parallel fibres. Ex., Gypsum and Asbestus.

Reticulated, with the fibres crossing and resembling a net.

Stellated, with fibres radiating from a centre and producing a star-like appearance. Ex., Stilbite, Wavellite.

Radiated and divergent, fibres radiating but not stellar. Ex., Quartz, Grey antimony.

2. *Laminated texture* exhibits laminæ or leaves (parallel plates), either thick or thin, separating easily or with difficulty.

Foliaceous, leaves thin and separating easily. Ex., Mica, whence this variety is sometimes called *micaceous*.

Tabular, laminæ thick. Ex., Quartz, Heavy spar.

The laminæ may be *elastic*, as in Mica; *flexible*, as in Talc or Graphite; or *brittle*, as in Diallage. They are also sometimes arranged in stellar shapes, as in Mica.

3. *Granular texture.* This term explains itself, and admits of the following varieties :—

Coarse Granular, as Granular marble.

Fine Granular, as Granular quartz, Specular iron.

Impalpable, as Chalcedony, Opal.

Friable, or easily crumbled by the fingers.

303. Massive minerals also take certain *imitative shapes,* not peculiar to either of these varieties. The following terms are used in describing them :—

Globular, when the shape is spherical, and the structure either radiating or concen-

tric. When they are attached in groups they are said to be *implanted*. Iron pyrites is often presented in this form.

Reniform, or kidney-shaped.

Botryoidal, when a mass consists of a number of rounded prominences like a bunch of grapes.

Mammillary, resembling the former, but consisting of larger prominences.

Filiform, like a thread.

Acicular, slender like a needle.

Stalactitic, cylindrical or conical, hanging from the roof of a cavern or cavity. Carbonate of lime, Brown iron ore, Malachite and Chalcedony, are the chief minerals found in a stalactitic form.

Drusy—a cavity is said to be drusy when it is lined with distinct crystals. A mineral having a drusy cavity is sometimes called a *geode*.

304. The *state of aggregation* of minerals exhibits another peculiarity of structure ; and in this sense solid minerals may be brittle, sectile, malleable, flexible, or elastic — terms which are used in the following senses :—

A mineral is called *brittle* if the particles lose their coherence and separate with a grating noise into powder, when we attempt to alter their respective situations in the substance. Of this kind are the gems, spars, pyrites, and many other minerals.

If a mineral is *malleable*, the particles, when detached by a knife, do not lose their connection ; so that from such a mineral we may detach slices, as from metallic lead.

Many minerals, such as Mica, cannot be sliced, and when cut, lose their mutual connection ; but instead of flying about remain quietly upon the instrument. These are called *sectile*, and are intermediate between *brittle* and *malleable*.

Minerals are *flexible* if the particles admit of their relative situations being changed and do not resume their former position ; and, lastly, they are said to be *elastic*, if, having been so changed, they resume their former situation when the force is removed.

305. The *fracture* of a mineral is a character that has sometimes been noticed, and, so far as it is distinguished from cleavage, is the irregular structure observable in breaking a mineral by violence in any direction. Sometimes the face presented by the broken mineral is round and smooth, resembling the inside of a shell, in which case it is called *conchoidal*. Other kinds of fracture are distinguished as *uneven*, *even*, *fibrous*, or *splintery* — terms which explain themselves, —and *hackly*, by which is meant the appearance presented when a metal such as gold is torn asunder. All regular fracture must be considered as cleavage.

306. The OPTICAL PROPERTIES OF MINERALS are such as depend on light, and are only observable in its presence. They include *colour* and *streak*, *lustre*, *transparency*, *iridescence*, *refraction*, and *polarisation*, and may unquestionably be of great importance in some cases.

307. By COLOUR is meant the colour of the entire mineral ; and this may be either metallic or non-metallic. The metallic colours are as follow :—*

* The subjoined table is from Hardinger's translation of "Mohs' Mineralogy." It will be found useful in many cases.

1. *Copper-red;* the colour of Native copper, and, less distinct, Copper-nickel.
2. *Bronze-yellow;* Iron pyrites.
3. *Brass-yellow;* Copper pyrites.
4. *Gold-yellow;* Gold.
5. *Silver-white;* Native silver, Arsenical pyrites (mispickel), Cobaltine.
6. *Tin-white;* Mercury, Native antimony, Native arsenic.
7. *Lead-grey;* Galena, Sulphuret of molybdenum, Vitreous silver.
8. *Steel-grey;* Native platina, Graphic tellurium.
9. *Iron-black;* Magnetic iron ore, Specular iron ore, Grey copper.

The following are non-metallic colours:—

WHITE.

1. *Snow-white;* Carrara marble, Arragonite.
2. *Reddish-white;* varieties of Calc spar and Quartz, Dolomite.
3. *Yellowish-white;* varieties of Calc spar and Quartz.
4. *Greyish-white;* Granular limestone.
5. *Greenish-white;* Amianthus, Talc.
6. *Milk-white;* Opal.

GREY.

7. *Bluish-grey;* Hornstone, varieties of Carbonate of lime.
8. *Pearl-grey;* Horn silver, Quartz, Heavy spar.
9. *Smoke-grey;* Flint (dark varieties).
10. *Greenish-grey;* Cat's eye and other varieties of Quartz, Mica.
11. *Yellowish-grey;* Compact limestone, Flint.
12. *Ash-grey;* Epidote, Leucite.

BLACK.

13. *Greyish-black;* Basalt, Lydian stone, Anthracolite.
14. *Velvet-black;* Obsidian, Schorl.
15. *Greenish-black;* Pyroxene.
16. *Brownish-black;* Coal, Mica.
17. *Bluish-black;* Black cobalt.

BLUE.

18. *Blackish-blue;* Azurite (dark varieties).
19. *Azure-blue;* Lapis lazuli (bright var.), Azurite (light var.)
20. *Violet-blue;* Amethyst, Fluor spar.
21. *Lavender-blue;* Lithomarge, Porcelain jasper (var.).
22. *Plum-blue;* Spinelle (rare var.), Fluor spar.
23. *Prussian-blue;* Sapphire (bright var.), Cyanite.
24. *Smalt-blue;* Gypsum (several var.).
25. *Indigo-blue;* Vivianite (phosphate of iron).
26. *Duck-blue;* (blue, with much green and a little black), Spinelle (var. Ceylanite) Talc.
27. *Sky-blue;* Liroconite (arseniate of copper), Fluor spar.

GREEN.

28. *Verdigris-green* (green much inclining to blue); Amazon stone.
29. *Celandine-green* (green with blue and grey); Chlorite, Beryl (var.).
30. *Mountain-green* (green with much blue); Beryl, Topaz, Aqua-marine.
31. *Leek-green* (green with a little brown); Prase.
32. *Emerald-green;* Beryl, Emerald, Malachite (var.)
33. *Apple-green* (light green with a little yellow); Chrysoprase.
34. *Grass-green;* Green diallage, Malachite, Uranite.
35. *Pistachio-green* (green with yellow and a little brown); Olivine, Epidote.
36. *Asparagus-green* (pale green with much yellow); Asparagus stone, Grossular (Garnet).
37. *Blackish-green;* Serpentine, Augite (var.).
38. *Olive-green;* Garnet, Pitchstone, Olivine, Pharmaco-siderite.

39. *Oil-green* (pale green with very little yellow and brown); Blende, Beryl, Pitchstone.
40. *Siskin-green* (light green very yellow); Uranite, Pyromorphite.

YELLOW.

41. *Sulphur-yellow*; Sulphur.
42. *Straw-yellow* (light yellow with a little grey); Topaz (var. Pycrite).
43. *Wax-yellow* (yellow with grey and a little brown); Common opal, Molybdate of lead.
44. *Honey-yellow* (yellow with a little red and brown); Calc spar, Fluor spar, Amber.
45. *Lemon-yellow* (purest yellow); Yellow orpiment, Uran ochre.
46. *Ochre-yellow* (yellow with brown); Quartz and Massive quartz, with Oxide of iron.
47. *Wine-yellow* (pale yellow with a little red and grey); Topaz, Fluor spar.
48. *Cream-yellow* (pale yellow with a little red and very little brown); Lithomarge.
49. *Orange-yellow* (yellow inclining to red); Molybdate of lead (var.).

RED.

50. *Aurora-red* (red with much yellow); Red orpiment.
51. *Hyacinth-red* (red with yellow and a little brown); Hyacinth, Garnet.
52. *Brick-red*; Stilbite, Porcelain jasper.
53. *Scarlet*; Cinnabar, Ruby-silver.
54. *Blood-red*; Pyrope-garnet.
55. *Flesh-red*; Heavy spar.
56. *Carmine*; Spinelle, Red oxide of copper.
57. *Cochineal-red*; Red silver, Garnet.
58. *Rose-red*; Rose-quartz, Carbonate of manganese.
59. *Crimson*; Ruby, Cobalt-bloom.
60. *Peach-blossom-red* (red with white and some grey); Lepidolite, Cobalt-bloom.
61. *Columbine-red* (red with a little blue and much black); Garnet.
62. *Cherry-red* (dark red with much blue and a little brown); Red antimony.
63. *Brownish-red*; Red ochre.

BROWN.

64. *Reddish-brown* (brown with much red); Blende, Zircon.
65. *Clove-brown* (brown with red and a little blue); Axinite, varieties of Quartz.
66. *Hair-brown* (brown with a little yellow and grey); Wood opal, Brown iron ore (hydrous oxide).
67. *Brocoli-brown* (brown with blue, red, and grey—rare); Zircon.
68. *Chesnut-brown* (purest brown); Egyptian jasper.
69. *Yellowish-brown* (brown with much yellow); Flint, Jasper.
70. *Pinchbeck-brown* (yellowish-brown with metallic lustre); Mica (several varieties).
71. *Wood-brown* (brown with yellow and grey); Amianthus (var. Mountain wood).
72. *Liver-brown* (brown with grey and a little green); Common jasper, Quartz, Cobalt-ochre.
73. *Blackish-brown* (brown with much black); Brown-coal.

308. Besides these there exist a great number of shades or varieties, which may be expressed by the indications of those two which they most nearly represent. Colours may also differ in intensity, and may be spoken of as *pale, light, deep,* or *dark,* according to their quality.

The varieties of colour occurring in the same species form uninterrupted series, which cannot well be described, but which deserve study. Fluor spar offers a good and simple example of this series

of colours. Several of the gems, as Diamond, Sapphire, Topaz, and Emerald also afford instructive series.

309. The *streak* is the appearance presented when a mineral is scratched with a sharp instrument, in which case either a powder is produced, or the scratched place assumes a higher lustre than before. The best method of observing the colour of the powder is to rub the mineral on a piece of porcelain biscuit or a file till the powder appears. Some minerals retain their colour in the streak, as spars, and white varieties generally; others change colour, as many oxides and sulphurets of metals; while others, again, are too hard to exhibit any change. R The student should be aware that a heap of very fine powder is white, whatever the substance from which it is obtained.

310. LUSTRE depends on the nature of the surface of a mineral, which causes light to be reflected in different ways and to a different extent. There are thus various *kinds* of lustre and many *degrees*.

There are six kinds of lustre, as follows :—

1. *Metallic*, the usual lustre of metals; imperfect metallic-lustre is expressed by the term, *sub-metallic*.
2. *Vitreous*, the lustre of broken glass. An imperfect vitreous lustre is termed *sub-vitreous*. Both the vitreous and sub-vitreous lustres are common. Quartz possesses the former in an eminent degree; Calcareous spar often shows the latter. This lustre may be exhibited by minerals of any colour.
3. *Resinous*, lustre of the yellow resins. Ex., Opal, Zinc-blende.
4. *Pearly*, like pearl. Ex., Talc, Native magnesia, Stilbite, &c. When united with sub-metallic lustre, the term *metallic-pearly* is applied.
5. *Silky*, like silk; it is the result of a fibrous structure. Ex., Fibrous carbonate of lime, Fibrous gypsum, and many other fibrous minerals, more especially those which in other forms have a pearly lustre.
6. *Adamantine*, the lustre of the diamond. When sub-metallic, it is termed *metallic-adamantine*. Ex., some varieties of White lead ore.

The degrees of intensity are denominated as follows :—

1. *Splendent*, when the surface reflects light with great brilliancy, and gives well-defined images. Ex., Elba iron ore, Tin ore, some specimens of Quartz and Pyrites.
2. *Shining*, when an image is produced, but not a well-defined image. Ex., Calcareous spar, Celestine.
3. *Glistening*, when there is a general reflection from the surface, but no image. Ex., Talc, Copper pyrites.
4. *Glimmering*, when the reflection is very imperfect, and apparently from points scattered over the surface. Ex., Flint, Chalcedony.
5. *Dull*. A mineral is said to be *dull* when there is a total absence of lustre. Ex., Chalk.

311. TRANSPARENCY is the property which many substances possess of transmitting light, and we have chiefly to observe with reference to it the relative quantity of light transmitted. These degrees are :

1. *Transparent*, allowing small objects to be distinctly seen.
2. *Semi-transparent*, allowing objects to be obscurely seen.
3. *Translucent*, allowing light to pass, but no object to be seen.

4. *Sub-translucent*, when the acute edges of a mineral allow some light to pass.
5. *Opaque*, not transmitting any light.

Few species of a non-metallic appearance are perfectly opaque, and some, though opaque in one direction, allow light to pass through them in another. Many minerals vary exceedingly in the degree of transparency they present.

312. Under the term IRIDESCENCE may be included a play, or change of colours, opalescence, tarnish, and other peculiarities, often very remarkable, and well distinguishing certain minerals. It is necessary to define these briefly.

Play of Colours, describes the condition when several prismatic colours appear in rapid succession on turning the mineral. They are well seen in the Diamond and in precious Opal.

Change of colour is seen as in Labradorite, when the colours alter slowly on turning in different positions.

Opalescence is seen when there is a milky or pearly reflection from the interior of a specimen, as in some Opals and in Cat's eye.

Iridescence occurs when prismatic colours are seen within a crystal. It is usually an effect of fracture, and is common in Quartz, Selenite, and sometimes in Calc spar.

Tarnish is when the surface-colours of a mineral differ from the true and internal colour. It is the result of exposure, and sometimes presents the hues of the rainbow. Peacock-ore (Copper pyrites) is an example.

313. POLYCHROISM is a property belonging to some prismatic crystals, presenting a different colour in different directions. The term *dichroism* is sometimes used, the colours occurring only in two directions, as in Iolite, hence called Dichroite. Mica is another example. The different colours are observed only in crystals with unequal axes. The colours are the same in the direction of equal axes, and often unlike in the direction of the unequal axes — a principle at the base of polychroism.*

314. REFRACTION and POLARIZATION of LIGHT. — A ray of light proceeding from any object, and passing from any one medium or transparent substance to another, is more or less bent out of its original direction, and this bending is called *refraction*. Thus, when a straight stick is held aslant in water it appears bent at the contact of air and water; and all transparent minerals bend aside rays of light to a certain extent, dependent on their structure. The index of refraction, therefore, or the measure of the extent to which light is bent aside on passing into a mineral, is one means of identifying it. The accidental colours presented by certain substances modify this measure, and in the cases of dimorphism referred to in the last chapter the refraction is different in the two forms assumed by the same mineral. Sir Isaac Newton suspected the true chemical composition of the diamond from observing its high refractive power.

315. When a ray of light is passed through certain minerals,

* Dana's "Manual of Mineralogy," p. 75.

instead of continuing its course as usual, after being bent aside on entering the new surface, it is separated into two parts, each part undergoing a different refraction and ultimately emerging by itself. An object seen through such a mineral appears double, and the phenomenon is called *double refraction.* It occurs very distinctly in Iceland spar, but extends to all crystalline minerals belonging to such of the fundamental forms as have unequal axes. When the object in these cases is seen through the vertical axis, it appears single, but in all other directions double. Double refraction affords a most important means of determining minerals, since it is derived from the intimate structure of the substance, and is not affected by the admixture of slight impurities. It is usual to consider one of the two rays transmitted after double refraction as the regular, and the other as the extraordinary ray. Generally, the extraordinary ray is further removed from the axis of the crystal than the other, but this is not always the case.

316. When light is thus refracted doubly the extraordinary ray exhibits a peculiar property, called *polarization*, and if afterwards viewed through a thin plate or slice of another doubly-refracting crystal, it becomes alternately visible and invisible as the latter plate is revolved, and it also presents a curious display of prismatic colours. Light may undergo this change of condition, or become polarized, by reflexion at a certain angle from most substances, or by passing through thick plates.

317. Phosphorescence.—The property of emitting light either by friction or when gently heated, is called *phosphorescence*, and is possessed by several minerals. It is exhibited in quartz by friction, light being readily evolved with a peculiar smell when one piece is rubbed against another, and the mere rapid motion of a feather across some specimens of Blende (sulphuret of zinc) will often produce light of more or less intensity. Although comparatively few minerals are phosphorescent by friction, many exhibit light of this kind when exposed to a certain temperature, and the light is often of different colours. Exposure to heat, however, destroys the phosphorescent power, although it may often be renewed by passing electric shocks through the calcined mineral, the light that then appears not being always of the same colour as before. Electricity has a very manifest power of increasing the intensity of natural phosphorescent light, and repeated electrical discharges have been known to communicate distinct shades of colour, permanent, at least for a time, to calcined minerals.

The diamond is remarkable for exhibiting distinct phosphorescence after being exposed for some time to the light of the sun.

318. Electricity, including also under this head Magnetism, in its reference to mineralogy, involves considerations concerning the

capacity of different minerals for the development in them, and the transmission through them, of electric currents. It also has reference to those instances in which electric force is exerted by a mineral in its natural condition, as in the case of the magnet.

A great many minerals are capable of having electricity developed in them by means of friction, but it appears that the kind of electricity thus induced has no reference to the characteristics of the minerals. Pressure even betwixt the fingers will excite distinct positive electricity in pieces of doubly refracting Calc-spar. Topaz, Arragonite, Fluor-spar, Carbonate of lead, Quartz, and other minerals, show the same property, but in a much smaller degree. Heat, or change of temperature, excites electricity in the following minerals,—Axinite, Prehnite, Boracite, Tourmaline, Calamine, Topaz, Sphene, Calc-spar, Beryl, Heavy-spar, Fluor-spar, Diamond, Garnet, and others.*

With regard to the power of minerals to conduct electricity many experiments have been made, and many results recorded, but no important general law seems to have been obtained bearing on the classification of minerals. It would seem that generally native metals are the best conductors, next the sulphurets, and then the oxides. Lustrous metallic crystals are said to be generally good conductors, and unmetallic crystals generally bad. Crystals often conduct differently in opposite directions, but some individual crystals would seem to be almost perfect non-conductors.

Many minerals exhibit electric polarity by the simple application of heat. This is the case most strikingly with tourmaline.

The following remarks, by M. Becquerel, concerning the development of electricity in the Tourmalin, are of some interest :—

"At 30° Cent., electric polarity was sensible ; it continued unchanged to 150° Cent., as long as the temperature continued to rise, but if stationary for an instant the polarity disappeared, and shortly manifested itself reversed, when the temperature began to decline. If only one end was heated the crystal was unpolarized, and when two sides were unequally heated each acquired an electrical state independently of the other."

319. Iron, Cobalt, Nickel, Iridium, and some other metals, are all attractable by the magnet in certain mineralogical states ; and some other minerals are so after exposure to great heat. The ordinary and manifest phenomena of polarity and attraction are confined, however, to a few ores, chiefly of iron. (See note p. 18.)

320. Odour is not possessed by any minerals in a dry unchanged state ; but it may be obtained from several by moistening with the breath, by friction, by heat, or by the application of acid. Amongst the most remarkable varieties are the following :—

Argillaceous, the odour of moistened clay, obtained from Serpentine, Chlorite and some allied minerals, by breathing upon them.

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* Nicol's "Mineralogy," p. 72.

Fetid, the odour of sulphuretted hydrogen, obtained from some varieties of Quartz and Limestone, by friction or a blow with the hammer.

Sulphurous, odour obtained by friction from Pyrites, and by heat, from most of the sulphurets.

Horse-radish odour, perceived when the ores of Selenium are heated.

Garlic-odour, obtained by friction from some, and by heat from most, of the arsenical salts and ores.

H.

321. The TASTE is a means of distinguishing many of the soluble minerals—the tastes of the salts of soda, of alum, of vitriol, &c., being well known and easily recognised. Many decomposed minerals, although they have no sensible taste, adhere more or less strongly to the tongue, and thus affect that organ.

The tastes of minerals are thus described :—

1. *Astringent*, having the taste of vitriol.
2. *Sweetish-astringent*, taste of alum.
3. *Saline*, taste of common salt.
4. *Alkaline*, taste of soda.
5. *Cooling*, taste of saltpetre.
6. *Bitter*, taste of epsom salts.
7. *Sour*, taste of sulphuric acid.

H.

322. HARDNESS is a very important and distinctive character of minerals ; but as it is of necessity a purely relative distinction, an acknowledged scale must be obtained, composed of well known minerals, of which each preceding one is scratched by that which follows it, while the latter does not scratch the former ; and care must be taken that the intervals are as equal as possible, and not so small as to render the employment difficult and uncertain, or so considerable as to give no definite conclusion.

The following is the scale that has been selected as possessing these properties:—

1. *Talc.*
2. *Gypsum*—*Rock-salt.*
3. *Calc-spar* (any cleavable variety).
4. *Fluor-spar* (any cleavable variety).
5. *Asparagus-stone* (from Salzburg, possessing a conchoidal fracture) or *Apatite* (transparent crystals).
6. *Felspar* (cleavable variety).
7. *Quartz* (limpid and transparent).
8. *Topaz* (any transparent crystal).
9. *Corundum* or *Sapphire* (the cleavable variety called *Corundum stone*).
10. *Diamond.*

Specimens of all these can be readily obtained with the exception of No. 5 ; but it has been found impossible to discover a substitute, and there is, also, too much difference between this and felspar (6). *Foliated mica* has been added between 2 and 3, and numbered 2·5, and a crystalline variety of *Scapolite* between 5 and 6 as 5·5.

323. The best use of the scale may be thus illustrated. The minerals of the scale having been selected pure, with natural cleavage faces, and having solid angles of the same form and edges in good condition, and the student, being provided with a fine, very hard, and well-tempered file, should try with a corner of the given mineral to scratch the members of the scale, beginning with the hardest. Having reached

the first that is distinctly scratched, he must have recourse to the file, and compare upon it with a very light touch the hardness of this degree, of the next higher degree, and of the given mineral. Care must be taken to employ specimens of each nearly agreeing in form and size, and also as much as possible in the quality of the angles. From the resistance opposed to the file, and the noise occasioned by their passing over it, we argue with perfect security upon their mutual relations in respect of hardness. The experiment is repeated with any alterations thought necessary till we consider ourselves arrived at a fair estimate, which is at last expressed by the number of that degree with which it has been found to agree most nearly, decimals being likewise added if required.

It must be mentioned, that those minerals which cleave readily in only one direction, often show a less degree of hardness on the perfect face of cleavage than in other directions. Such minerals can be only properly determined, in respect of hardness, by attending to this peculiarity.*

324. Specific Gravity.—The relative weight of bodies is expressed in common language by saying that one is heavier than another, meaning that if the two substances have the same form and dimensions, there is a greater pressure downwards in the one case than the other. Thus a cubic inch of lead weighs much more than a cubic inch of wood; but as both would displace the same quantity (one cubic inch) of water, if placed in a vessel full of that fluid, both may be measured against and compared with water as a standard.† The relative weights thus obtained are called *specific gravities;* and the specific gravity of a mineral is often of very great importance in determining its nature and place in the series.

325. The following methods of finding the specific gravity of solids will be found convenient:—

If the specimen is large enough to be suspended conveniently by a thread, weigh it first in air by a fine balance, expressing the result in grains, and taking care previously to remove dust or loosely-adhering particles. Then suspend it by a horsehair from the scale-pan (it is convenient to have a hook attached to it for this purpose), and thus suspended, immerse it and re-weigh it in water, taking care that it is covered on all sides by at least half an inch of water, and carefully brushing off with a feather any bubbles of air that adhere to the surface. The results may then be noted as follows:—

Weight of substance in the air in grains	
Deduct weight of ditto in water	
Difference	

This result gives the weight of a bulk of water equal to that of the specimen, and

* We have given this rather full account of the mode of determining hardness, which is chiefly taken from Haidinger's translation of "Mohs' Mineralogy," believing that as an approximate method it may have great value when others are not readily available.

† Distilled water at a temperature of 60° Fahr. is the standard usually employed.

by dividing the weight of the specimen in air by this number, the specific gravity is obtained.

$$\text{Specific gravity} = \frac{\text{weight of substance in air}}{\text{weight of equal bulk of water.}}$$

If, however, the substance is in the form of fine sand or very small lumps, it is better, after weighing it carefully, to take a small dry phial furnished with a stopper, counterpoise this phial accurately in the weight scale by shot or strips of lead, then fill it completely with pure water, taking care that no bubbles of air are left in, and weigh the quantity of water it contains: afterwards empty the bottle and dry it inside.

Next fill the bottle about two-thirds full of the powder to be examined, weigh this and record the weight. Then fill the bottle once more with water, taking care, as before, that all bubbles are expelled and none of the powder washed out. Once more weigh it.

We have then to make the following calculation:—

Weight of powder and water in grains	=
Deduct weight of powder alone	=
Difference (weight of water left in bottle)	=
Weight of bottle full of water in grains	=
Weight of water left in bottle	=
Difference (weight of water displaced by, and equal in bulk to, powder)	=

$$\text{The specific gravity} = \frac{\text{weight of powder in air}}{\text{weight of water displaced.}}$$

326. The minerals of which we intend to find the specific gravity, must be perfectly pure, and the greatest care should be taken to remove, as much as possible, whatever heterogeneous substances may adhere to them, or, at least, we should consider and mention the probable influence of such admixture on the correctness of the results. All the vacuities, also, or empty spaces within the specimens, should be carefully opened; and in order to get rid of these it will be necessary, in some cases, to have the minerals broken down till we can no longer detect a want of continuity in the fragments.*

327. The CHEMICAL COMPOSITION of minerals must be determined by a process of chemical analysis, which it is not the object of the present work to describe. We shall here merely allude to the simplest and most usual means of detecting some characters which may lead at once to a knowledge of the mineral without complete analysis. These means involve the use of acids and alkalis, and also the appearance of minerals when exposed to heat under a blow-pipe, either alone or with certain salts called fluxes. Many minerals which exhibit no distinct crystalline form, and no sufficient external physical characters, may still be readily distinguished by very simple operations of this kind.

328. *Water* alone is sometimes employed in the determination of minerals, but its use is limited to a few soluble salts; for although some stony minerals, as sulphate and carbonate of lime, and even

* Bowman's "Practical Chemistry," p. 41.

silex, are no doubt soluble to some extent in water, the proportion is too small to afford any practical indication.

329. *Acids* offer a far more valuable and important test, and in many minerals produce immediate decomposition. The acids employed are either sulphuric, muriatic (hydrochloric), or nitric, generally mixed with more or less water, and applied either at the ordinary temperature or with heat. The points to be determined and observed when the acid is applied, are

1. Whether the mineral is acted on and dissolved by the acid.
2. Whether if so it is dissolved with effervescence.
3. Whether the whole mineral is at length dissolved, or an earthy or gelatinous residue obtained.

In the first case the action may be either rapid or slow, and the resulting solution either coloured or colourless—a result of considerable importance, since a green solution almost always arises from the presence of copper; a pink, or rose-coloured solution from cobalt, &c.

330. With regard to substances that dissolve with effervescence both the kind and intensity of effervescence should be noticed. Native copper, Copper pyrites, and other native metals, metalliferous ores not oxides, and some in which the proportion of oxygen is small *(protoxides)*, give off nitrous acid vapours when dissolved in nitric acid, and may be at once distinguished—thus, *Pitch blende* is immediately distinguished from *Wolfram* by this experiment. It is important to notice whether the effervescence is accompanied by any odour, and if the gas evolved is coloured.

In many cases the effervescence takes place without colour or odour, as happens with the carbonates, which are entirely dissolved, their carbonic acid being liberated in the form of gas. In *Carbonate of lime* the action is extremely rapid and violent; in *Dolomite* very slow, and generally it only commences a minute or two after the substance in a state of powder has been thrown into the acid. The degree and kind of effervescence at once distinguishes several nearly allied and very similar minerals.

331. Many substances are only partly soluble, leaving a distinct residuum, while others exhibit a gelatinous, transparent mass, floating like a cloud in the solution. The hydrosilicates often exhibit this property, the floating jelly being the hydrate of silica. *Nepheline*, *Meionite*, and other minerals (generally zeolites—see § 417), are good examples. It is useful sometimes to observe the proportion and nature of the residue, as in this way, for example, the difference between pure and argillaceous carbonates of lime may be detected, a point of some consequence in determining the value of limestone for the manufacture of cement.

332. *Alkalis* are occasionally, though very rarely, resorted to by the mineralogist for the determination of species; some minerals, as

horn-silver, being soluble in caustic ammonia, and caustic potash affecting the silicious jelly obtained by the solution of the hydrosilicates in acid.

333. The application of HEAT is extremely important in determining minerals; and this may be effected either by calcining or roasting, to discover and drive off volatile substances; by the application of stronger heat to produce fusion; and by observing the results of fusion.

Some minerals, such as Native bismuth, Sulphuret of silver, Cryolite, &c., are at once reduced to the fluid state on exposure to the flame of a taper, or a jet of burning gas; but this is not generally the case, and a much higher temperature is required to obtain useful results. The usual and most convenient means of gaining this end is to concentrate the flame by a blow-pipe, a bent tube terminating with a fine orifice, through which common air or some gas is forced. In this way a blast being obtained, and the heat of a flame brought to bear on any required object, the behaviour of the mineral may be well and minutely observed. It is no part of the intention of the present work to give minute instructions on a subject of this kind, and we shall, therefore, quote the brief, but distinct notice of the use of the blow-pipe from Professor Dana's "Manual of Mineralogy," referring to larger and more complete treatises on blow-pipe analysis for further information and practical results.*

334. In using the blow-pipe it is necessary to breathe and blow at the same time that the operator may not interrupt the flame in order to take breath. Though seemingly absurd, the necessary tact may easily be acquired. Let the student first breathe a few times through his nostrils while his cheeks are inflated and his mouth closed. After this practice let him put the blow-pipe to his mouth and he will find no difficulty in breathing as before, while the muscles of the inflated cheeks are throwing the air they contain through the blowpipe. When the air is nearly exhausted, the mouth may again be filled through the nose, without interrupting the process of blowing.

A lamp with a large wick, so as to give a broad flame, and fed with olive oil, is best; but a candle is more conveniently carried about when travelling. The wick should be bent in the direction the flame is to be blown.

The flame has the form of a cone, yellow without and blue within. The heat is most intense just beyond the extremity of the blue flame. In some trials it is necessary that the air should not be excluded from the mineral during the experiment, and when this is the case, the *outer* flame is used. The outer is called the *oxidating* flame, and the inner, the *reducing* flame.

The mineral is supported in the flame either on charcoal, or by means of steel forceps with platinum extremities. The charcoal should be firm and well-burnt. Charcoal is especially necessary when the reduction of the assay needs the presence of carbon; and platinum when simple heat is required. Platinum foil for enveloping the mineral, and small platinum cups are also used. When nothing better is at hand

* One of the most important works on the subject is that of Plattner, which has been translated into English by Dr. Muspratt. The extreme beauty and accuracy of its results have raised blow-pipe analysis into a distinct branch of chemical science, whose practical conclusions are invaluable, and in many cases are more to be depended on than those from any other method of assay or analysis.

the mineral Mica, or Cyanite may be employed. The fragment of mineral under trial should be less than half a pea in size, and often a thin splinter is required.

To test the presence of water, or a volatile ingredient, the mineral is heated in a glass tube or test vial. The tube may be three or four inches long, and as large as a quill. The flame is directed against the exterior of the tube, beneath the assay, and the volatilized substance usually condenses in the upper part of the tube. By inserting into the upper end of the tube a strip of litmus or other test-paper, it is ascertained whether the fumes are acid or not. The substances thus driven off are water, oxygen gas, mercury, sulphur, arsenic, &c.

335. Some species require for fusion the aid of what are called *fluxes*. Those more commonly used are borax, salt of phosphorus, and carbonate of soda. They are fused to a clear globule, to which the mineral is added ; or powdered and made up into a ball with the moistened mineral in powder. In this way some minerals are fused that cannot be attacked otherwise ; and nearly all species as they melt undergo certain changes in colour, arising from changes in composition, which are mentioned in describing minerals.

The above-mentioned fluxes, also, are often required in order to obtain the metals from the metallic ores. On heating a fragment of copper pyrites with borax, a globule of copper is obtained ; and tin ore heated with soda yields a globule of tin.*

336. The composition of minerals when learned by analysis generally presents some substances which may be regarded as non-essential to the perfect crystalline condition, and thus the true value and chemical determination of the mineral is not at once obtained. The application of the theory of chemical proportions will, however, generally be sufficient to show clearly what is essential and what is accidental. Thus, for example Calc spar in its purest form of Iceland spar is found to consist of

Carbonic acid	43·71	100·00.
Lime	56·29	

and if this is reduced to show the atomic relation, we shall find that the real proportion is two atoms of carbonic acid to one atom of lime, which represents the true nature of the mineral. But if we take a piece of common limestone it may give such an analysis as the following :

Carbonic acid	35·41	100·00.
Lime	45·59	
Clay	15·40	
Oxide of iron	3·60	

And here at first there seems little resemblance ; but if we carry the calculation a little further, we shall find that the 35·41 parts of carbonic acid in this latter analysis contain 25·58 of oxygen, while the 45·59 of lime contain 12·80 ; the proportion being still 2 : 1, and the minerals, therefore, identical. The existence of impurities and foreign substances in minerals often greatly confuses the analyses obtained, and it requires great care to avoid error. Generally no species can be admitted in mineralogy as well established in which atomic relations cannot be traced very clearly, and where these do not recur in every fair instance. In the example before us the

* Dana's "Manual of Mineralogy," *ante cit.* p. 68.

simple relation of one atom of oxygen in the base to two atoms in the acid establishes the species distinctly, and every instance in which this relation exists is only a variety of the species, even if it present peculiar physical characters.

337. The substances found in nature in a simple state have been already indicated (see ante § 8), as well as the other elementary substances hitherto determined by chemists. The elements generally are capable of combining in definite proportions of one and one, two and two, three and three, one and two, one and three, two and three, and so on ; but although the whole number of possible combinations is thus almost infinite, those really occurring in minerals are extremely few, and comparatively speaking, are simple—most of them being binary combinations, or including only two elements in their purest form, and even the possible number of these being greatly reduced by two conditions.

338. One cause of the limitation of mineral species is, that only thirteen of the elementary substances, as at present known, are essential in natural combinations. In other words, no natural combination exists without some one of these substances, and the number of compounds is thus reduced considerably. The following are the substances : Oxygen, Sulphur, Selenium, Chlorine, Fluorine, Carbon, Silicium, Tellurium, Arsenic, Antimony, Gold, Osmium, Mercury.

339. The other limiting cause is the extreme simplicity of the laws which appear to govern natural combinations of the inorganic kingdom, a single atom of one element in combination with one or more of another being far the most common case, and the combination of two atoms of one with three of another element being the proportion which may be regarded as next in abundance. Occasionally, no doubt, we meet with instances of greater complication, as where three atoms of one element combine with four of another, but such minerals are rare, and no examples more complicated than these are at present known.

340. Frequent instances occur of what are called 'compound atoms' obeying similar laws of combination to those just alluded to. Thus, in the case of Iceland spar already mentioned, the mineral may be regarded as made up of two compound atoms of carbonic acid and one of lime—the compound atoms consisting in the one case of two atoms of oxygen and one of carbon, and in the other of one atom of oxygen and one of carbon. It is often convenient to be able to express the compound atoms more simply than in the method already explained. This is done by employing Italic characters to mark the compound, and Roman letters the simple atoms. Thus, Ca signifies Calcium, and *Ca* lime. (CaO.)

Referring to the table before quoted (§ 8) we find the chemical equivalents or atomic weights of Oxygen (O) to be 8, of Carbon (C) 6, and of Calcium (Ca) 20. Hence, Carbonic acid is represented by (2O+C=16+6=) 22 ; Lime, by (Ca+O =20+8=)28 ; and Carbonate of lime by (carb. acid+lime=22+28=) 50. In many cases the proximate elements (as the carbonic acid and lime are also sometimes called) are those which it is most essential to discover in a mineral, and for this reason it has been thought well to allude to it here.

In thus recurring once more, and for the last time, to the subject of chemical combination and the laws that influence it, we would impress upon the student of geology the absolute necessity of such preliminary acquaintance with the laws of chemistry before attempting to learn the actual phenomena of rocks. All the important and widely-spread masses of mineral matter that make up the solid portion of the earth's crust are modifications of certain simple minerals combined and metamorphosed in accordance with the laws we are here attempting to enunciate. Chemistry is in this sense elementary to geology; although, perhaps, the highest and most important problems in geology can only be solved ultimately by the aid of the chemist.

341. When binary compounds, of which oxygen is one element, are decomposed by galvanic action, the oxygen is always liberated at the positive, and the other element (then called the base), at the negative pole. As it is well known that electricities of the same nature are mutually repellent, the name electro-negative is given to those elements that proceed to the positive, and electro-positive to those which appear at the negative pole. Oxygen is the only element that is constantly presented at the positive pole, all others being positive or negative according to circumstances; sulphur and arsenic, for example, being positive with respect to oxygen, and negative with regard to other elements.

342. Amongst the thirteen elements, one of which is essential to all binary combinations, two are far more abundant than the rest—namely, oxygen and sulphur; the former being not only present, but forming a very important proportion of the whole mass, in every one of the rocks of which the earth's crust is made up, and the latter almost equally important in reference to the metalliferous minerals which form useful ores. Oxides and sulphurets are the most abundant as well as the most widely distributed binary compounds.

343. Ternary combinations are generally composed of two binary combinations which have a common element; thus carbonate of lime is of this kind; and this, as well as most others, is formed of two compound elements, of each of which oxygen is one, or else of two combinations, each containing sulphur.

In this and many ways, as well as by the limitation in the number of the atoms which combine, the total number of minerals is greatly limited, and the number of natural groups is brought within very easy and distinct description.

344. The most common of all minerals, and the most abundant in quantity, are either oxides, carbonates, or sulphurets, or, in other words, are bodies in which oxygen, carbonic acid, and sulphur are combined with other elements or proximate elements, so as to form binary or ternary compounds. We also find silicates presented in nature very generally, while fluates, borates, aluminates and phosphates almost complete the list. The remaining minerals naturally formed and at present known, are either modifications of those already named, or else examples (such as chromates, tantalates, and others where the base combined with oxygen forms an acid, which afterwards

combines with some other base or binary compound), bearing a distinct relation to these, although occasionally somewhat complicated.

345. Numerous systems have been suggested and adopted by different authors for classifying minerals, all of them subject to many and great inconveniences, since all separate by wide intervals substances having manifest relations, and bring together others which have few manifest and important resemblances. Some of these are sanctioned by names of the highest authority, but being based on theoretical views not universally admitted they have not obtained general assent. The plan which will be adopted in the following pages is chiefly founded upon the chemical nomenclature of M. Dufrénoy, and in it the number of minerals is reduced as much as seems justifiable. In the subsequent descriptions the unimportant species are merely named, but the names are, when necessary, accompanied by as full a list of synonyms as is likely to be useful. The total number of species referred to will be found to amount only to about 350, about 150 of which are merely named. A large number are omitted as only determined by the chemist, and belonging, therefore, to the domain of chemistry rather than geological mineralogy.

The principle of classification thus adopted is essentially chemical, the crystalline form being referred to only as a useful distinctive character in certain cases. The metals are collected together and described in groups easily referred to; the earthy minerals are also arranged in a manner which seems both natural and convenient, and the various simple salts forming ternary compounds are collected into their principal groups. The method is no doubt partly artificial, but it is to a great extent natural and easily understood.

346. Of other methods of classification it is not perhaps advisable to say much. Those in which form and structure are chiefly regarded differ in principle from the one here adopted, and are more purely artificial. An endeavour has been made by Dufrénoy, and apparently with some success, to frame a system which shall be at least natural in the great majority of cases. Some exceptions may be recognised, as in the case of the Silicates, since it is difficult to exclude the Silicates of iron, copper, and other metals from Class IV., and almost equally difficult to include them and yet preserve the groups of metalliferous minerals entire.

Many cases also occur in which the number of bases is so large, and the predominant influence of any one so slight, as hardly to justify the mineralogist in excluding the same mineral from several groups. Isomorphism interferes occasionally by substituting one element for another, and concealing the real nature of the chemical constitution of several remarkable and abundant substances.

The general principles of the method adopted will be understood by reference to the subjoined outline.

347. *Table of the Classification of Minerals.*

CLASS I. Simple bodies or binary compounds, never bases, generally essential ingredients in combinations, and serving as proximate elements.

Group 1. Hydrogen.
„ 2. Carbon.
„ 3. Silicium.
Group 4. Sulphur.
„ 5. Selenium.

CLASS II. ALKALINE SALTS.

Group 1. Salts of Ammonia.
„ 2. Salts of Potash.
Group 3. Salts of Soda.

CLASS III. ALKALINE EARTHS AND EARTHS.

Group 1. Salts of Barytes.
„ 2. Salts of Strontia.
„ 3. Salts of Lime.
Group 4. Salts of Magnesia.
„ 5. Salts of Yttria.
„ 6. Salts of Alumina.

CLASS IV. SILICATES.

Group 1. Anhydrous aluminous Silicates.
„ 2. Hydrous aluminous Silicates.
„ 3. Silicates of Alumina and Lime or their isomorphs.
„ 4. Aluminous and alkaline Silicates and their isomorphs.
„ 5. Hydrous aluminous Silicates with alkaline and lime bases and their isomorphs.
„ 6. Non-aluminous Silicates.
a. with Lime as a base.
b. with Zircon as a base.
c. with several bases.
„ 7. Silico-aluminates.
„ 8. Silico-fluates.
„ 9. Silico-borates.
„ 10. Silico-titanates.
„ 11. Silico-sulphurets.
„ 12. Aluminates.

CLASS V. METALS.

Group 1. Cerium.
„ 2. Manganese.
„ 3. Iron.
„ 4. Chromium.
„ 5. Cobalt.
„ 6. Nickel.
„ 7. Zinc.
„ 8. Tellurium.
„ 9. Cadmium.
„ 10. Antimony.
„ 11. Arsenic.
„ 12. Mercury.
„ 13. Titanium.
„ 14. Tantalum.
„ 15. Niobium.
„ 16. Pelopium.
Group 17. Ilmenium.
„ 18. Lead.
„ 19. Tin.
„ 20. Bismuth.
„ 21. Uranium.
„ 22. Tungsten.
„ 23. Molybdenum.
„ 24. Vanadium.
„ 25. Copper.
„ 26. Silver.
„ 27. Gold.
„ 28. Platinum.
„ 29. Iridium.
„ 30. Osmium.
„ 31. Rhodium.
„ 32. Palladium.

CHAPTER IX.

DESCRIPTION OF NON-METALLIC SIMPLE MINERALS.

348. We now commence the description of minerals, and, in order that the account may be as distinct, and at the same time as useful as possible, we propose to mention in most cases the chemical composition of the mineral, its hardness, its specific gravity, and the system in which it crystallises, using sometimes certain convenient symbols to shorten the description and avoid the constant repetition of the same expressions. The chemical composition will be given sometimes in full, but frequently according to the method indicated in the first chapter (see § 8), water being represented by the symbol Aq instead of HO, and the symbols printed in italics representing the combination of the element referred to with its full proportion of oxygen. Hardness is indicated by the letter H, and the degree of hardness by figures referring to the table inserted below. The specific gravity is marked by SG.

Table of Hardness.

1 = Talc	6 = Felspar.
2 = Gypsum or Rock-salt.	7 = Quartz.
3 = Calc-spar.	8 = Topaz.
4 = Fluor-spar.	9 = Corundum.
5 = Apatite.	10 = Diamond.

Table of Crystalline Systems.

1 Octahedral, or Regular.	4 Rhombic, or Prismatic.
2 Square prismatic.	5 Monoclinic.
3 Hexagonal, or Rhombohedral.	6 Triclinic.

CLASS THE FIRST.

349. The minerals included in this class are electro-negative bodies, never appearing as bases, and always forming an essential ingredient in binary combinations. Some of them (Oxygen, Hydrogen, Nitrogen, Chlorine) form permanent gases, either alone or in combination with other substances of the same group. Others, as Carbon and Sulphur, are sometimes conveniently considered in their character as combustibles, and others, again, will be described amongst metals. Lastly, there are many not found, except in combinations which must be referred to the group of Silicates. To the present class must be referred several elementary substances not met with in nature uncombined, but we only mention those which are important.

HYDROGEN.

Hydrogen Gas (H), disengaged during volcanic eruptions.

Sulphuretted Hydrogen (HS), found in certain mineral waters.

Carburetted Hydrogen (HC), marsh gas ; fire damp of coal mines.

Water (HO or *Aq*.)

CHLORINE.

HYDROCHLORIC ACID (HCl), emitted in volcanic districts.

CARBON.

350. This substance occurs in nature as a simple mineral in no less than three distinct forms, two of them, Diamond and Graphite, crystallizing in different systems; and the third, though massive and amorphous, quite unlike either of the others in many important characters. With the exception of the two crystalline forms, the various minerals of which carbon is a principal ingredient, burn at a low temperature, with flame and sensible odour. They are mostly derived from organic substances, and consist of combinations of carbon with hydrogen, and occasionally sulphur. They are conveniently distinguished as resins, bitumens, and coals.

351. DIAMOND (Octahedral, C, $H=10$, $SG=3{\cdot}5-3{\cdot}6$). The diamond is the crystalline form of pure carbon. It usually appears in regular octahedrons, whose specific gravity is 3·55. It burns with a bluish flame, and is consumed at a high temperature. It is the hardest known substance, and the one of greatest value when pure, of good colour, and of fair dimensions. It becomes electric by friction. Diamonds are found in various parts of the East Indies, in Brazil, in the Ural Mountains, and in Africa, generally in a quartzose conglomerate. The colour of the most valuable of these gems is blue, green, or red—the latter, a rose tint, when the diamond is in other respects good, obtaining the preference. A black variety occurs, but is very rare. The purest of all are limpid. Diamonds are estimated according to their weight in carats, one carat being nearly equal to four grains troy. The largest known specimen weighed, before cutting, nearly six ounces troy.

Besides its value as an ornament, the diamond is exceedingly valuable for the purposes of engraving and cutting glass, and advantage is taken of the frequent curvature of the crystalline faces to produce the hardest cutting edge. The grinding and cutting of the diamond is effected by hand, by the mutual friction of two specimens, assisted by the powder of the same substance.

352. GRAPHITE (Hexagonal, C, $H=0{\cdot}5-1$, $SG=1{\cdot}9-2{\cdot}245$) is generally regarded as an allotropic form of carbon, which thus appears to be dimorphous. It is also called *Plumbago* or *Black lead*, and has been regarded as a Carburet of iron, but in its pure state it consists of 95 to 96 per cent. of pure carbon, and $2\frac{1}{2}$ per cent. of other matters, chiefly lime and alumina. Its specific gravity varies a good deal, but the purest varieties are the lightest. Graphite is crystalline either in little plates or small hexagonal spangles. It is generally laminated or granular. In its pure state it is very valuable, but extremely rare. In an impure state it is common, and

generally found in lumps in altered rocks. Its uses in the arts are various—the best specimens are cut into thin strips for the manufacture of artist's pencils. A large quantity is employed in polishing, and in making crucibles for chemical purposes. The best specimens are from Cumberland, but the chief supply from Mexico and Ceylon.

Coal Sub-Group.

353. Anthracite (Amorphous, C, $H = 2 - 2{\cdot}5$, $SG = 1{\cdot}4 - 1{\cdot}7$) has a semi-metallic lustre. It burns with difficulty. It contains from 70 to 90 per cent. of carbon, and six to eight per cent. of volatile substances, generally consisting of incombustible ashes, of which Silicate of alumina forms a large part. There is a pure vitreous variety, perfectly homogeneous, and of distinct conchoidal fracture, but the common kinds are mixed with foreign matter. It appears to be a third, but uncrystallized form of carbon, and is found both in veins and beds, sometimes in altered rocks, and with metalliferous ores. The following is an analysis of Anthracite from Wales :—Carbon 92·56, Hydrogen 3·33, Oxygen and Nitrogen 2·53, Ash 1·58.

354. Bituminous Coal is less hard, more laminated, much richer in volatile ingredients, and much more readily inflammable than anthracite, containing from ten to thirty per cent. of matter chiefly volatile. It is abundant in certain localities, and is the kind chiefly used as fuel. The *Caking coal* is the kind obtained chiefly at Newcastle. *Splint coal* and *Cherry coal* are the names of varieties. *Cannel coal* is compact and of even texture, with little lustre. It burns freely like a candle, without swelling. *Jet* is still harder, of deeper colour and higher lustre. It is set in jewellery, receiving a high polish. It contains about $37\frac{1}{2}$ per cent. of volatile matter. The principal localities of coal and other economical facts will be given in a future Chapter.

The following analyses may be useful. They are chiefly those obtained lately under the superintendence of Dr. Lyon Playfair :—

	Locality.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.
Welch Coal..	Ebbw Vale....	89·78	5·15	2·16	1·02	0·39	1·50
Ditto	Coleshill......	73·84	5·14	1·47	2·34	8·29	8·92
Scotch ditto..	Dalkeith	74·55	5·14	0·10	0·33	15·51	4·37
Ditto	Grangemouth..	79·85	5·28	1·35	1·42	8·58	3·52
English ditto.	Forest of Dean.	73·52	5·69	2·04	2·27	6·48	10·00
Westphalia Coal		96·02	0·44		——	2·94	0·60
French Coal..	Blanzy	76·48	5·23		16·01		2·28

355. *Lignite or Brown-coal*, also called *Bovey-coal* and *Wood-coal*, is much less pure than bituminous coal, and usually contains water as well as rather a large proportion of earthy ash. There are many varieties, and the quantity of matter given off at a moderate heat by distillation, is at least equal to that of the carbon contained. *Dysodil* is a yellow or greyish highly laminated substance often found with Lignite, burning vividly and spreading an odour of asafœtida.

Bitumen Sub-Group.

356. BITUMEN. *Naphtha, Petroleum, Mineral Pitch, Asphalt, Mineral oil.* (CH_2, generally fluid, SG=0·7—0·9). These are names given to various forms of bitumen, consisting of compounds of carbon and hydrogen, found both solid and fluid in nature, and presenting no regular form. Some of them, as Petroleum, ooze from rocks of the coal formation, and harden on exposure; and even Naphtha, which is a limpid or yellowish fluid, issuing from the earth in large quantities in Persia and the Birman empire, also blackens and hardens in the course of time. Lakes of bitumen exist in the Isle of Trinidad, issuing at a high temperature, boiling in the middle, but solid and cold near the shores.

The variety called *Asphalt* is met with abundantly on the shores of the Dead Sea, but it also occurs in the Pyrenees, and has been obtained from thence to mix with gravel, and form a pavement. It has a conchoidal fracture, is sectile, H=2, SG=1·1—1·2. It is opaque and resinous, and has a strong bituminous odour when rubbed.

357. MINERAL CAOUTCHOUC. *Elastic Bitumen, Elaterite.* (CH_2. Very soft. SG=0·8—1·23.) It occurs in soft, flexible masses of brownish black colour, consisting when pure of 85½ per cent. of carbon, and 13·3 per cent. of hydrogen. It burns readily with yellow flame and bituminous odour. *Idrialine* is a variety containing upwards of 94 per cent. of carbon, and represented by the formula C_3H_2.

Resin Sub-Group.

358. AMBER ($C_{10}H_8O$, H=2—2·5, SG=1·08). It occurs in irregular transparent masses, of yellow colour and resinous lustre. Consists of carbon 79, hydrogen 10·5, oxygen 10·5. Burns with yellow flame and aromatic odour. It is used for ornamental purposes, for pipe-heads in Turkey, and yields when burnt a carbonaceous residue, whence the finest black varnish is coloured. It is highly electric by friction. It is unquestionably of organic origin, and is chiefly found on the shores of the Baltic between Königsberg and Memel. It often contains the remains of insects, and sometimes even the most delicate parts of flowers.

RETINITE, *Retin-asphalt,* occurs in roundish subtransparent masses of earthy lustre on lignite. It is a mixture of a vegetable resin with bitumen.

Fossil Copal, a native resin found at Highgate, and elsewhere. *Berengelite, Guyaquillite, Middletonite, Piauzite,* are other names for similar fossil resins.

MOUNTAIN TALLOW and *Hatchetine* are the names given to substances intermediate between resins and bitumens. They have generally resulted from the decomposition of organic substances.

Scheererite, Fichtelite, Konlite, Hartite, Ixolite, Ozokerite, are the names of varieties differing in the proportion of carbon and hydrogen. *Mellite* is sometimes regarded as a resin and sometimes as a salt of alumina. See § 398.

CARBONIC ACID GAS (CO_2 or C). Abundant in mineral waters and volcanic districts.

BORON.

Boracic Acid ($\ddot{B}$+Aq.) found in certain mineral waters.

SILICIUM.

359. Quartz (SiO_3 or $\dddot{Si}$, Hexagonal, H=7, SG=2·65–2·8). One of the most abundant substances in nature, and one whose different forms are very frequently presented to the mineralogist. It consists exclusively of silica. It strikes fire with steel, and scratches glass and most other substances, except a few gems. It is infusible before the blow-pipe, and insoluble in ordinary acids. The following division into five sub-species will be found useful :—

1. Rock Crystal.
2. Compact Quartz.
3. Agate.
4. Flint.
5. Earthy Quartz.

360. Rock Crystal, Amethyst, and some other varieties of Quartz, are crystalline and highly transparent, with distinct and well-marked vitreous fracture. The amethystine varieties (*Amethyst* and *Rose quartz*) contain alumina and oxide of manganese, and the *Cairngorm* or *Smoky-quartz*, a small quantity of bitumen. White varieties, (*Milky-quartz*), are phosphorescent when rubbed together, and give out a strong odour. *Ferruginous quartz* is coloured with iron, and is remarkable for often presenting well-shaped crystals.

The general form of quartz-crystals is a regular six-sided prism, terminated by six-sided pyramids; but the usual crystals are modifications of this original form, although frequently retaining a distinct trace of it. Cleavage is rarely traceable by ordinary means, but may often be detected by heating a crystal and plunging it in water. The tendency of cleavage is to produce the fundamental form, of which perfect specimens are extremely rare. Quartz exhibits double refraction to a moderate degree.

Rock crystal is frequently penetrated by acicular crystals of titanium, by crystals of asbestus, producing the mineral called *Cat's-eye*, and by crystals or plates of mica, as in the case of *Avanturine*. The latter is a rare mineral in nature, the specimens sold being usually factitious. A fluid has been observed occupying cavities in quartz crystals, which was at one time supposed to be water; but Sir David Brewster has shown it to consist of two oleaginous liquids volatile at different temperatures. *False-topaz* or *Eitrine*, is a name given to pale, yellow, pellucid crystals of quartz resembling topaz.

Compact Quartz, or *Quartzite*, is the name given to metamorphic sandstones found in the Alps and elsewhere. *Granular-quartz* is an earthy form of it. *Sandstone* passes into granular quartz and quartzite, and will be described in a future chapter as a rock.

361. Agate is a stalactitic or concentrically-formed quartz, frequently presenting distinct and beautiful coloured bands. Agates are called by various names according to their appearance, structure, or colour; thus, when undulating and many-coloured, they are *Riband-agates;* when zigzag, *Fortification-agates;* and when apparently broken, *Ruin-agates*. When the colours and bands are not very numerous, but arranged in flat horizontal layers, the name *Onyx* is given to them, and they are then employed for cameos, one colour being partly removed in the process of manufacture. When the colours are mixed irregularly, the specimens are called *Mocha-stones* or *Moss-agates*, and present the appearance of enclosed vegetation, generally due to the imperfect crystallisation of colouring salts of manganese or iron.

362. Agate, when of pearly or smoky grey colour, subvitreous or waxy lustre, great translucency, and clear tint, is called *Chalcedony*, and specimens presenting a blood-red colour, either uniformly distributed or in patches, are *Carnelians*. These are much used in the less-expensive kinds of jewellery, and the colours are gene-

rally deepened by long exposure to the sun's rays. *Sard* is a deep brownish-red, and *Chrysoprase* an apple-green variety, the latter coloured by nickel; while a peculiar dark green quartz mineral of this kind, spotted as if with drops of blood, is called *Heliotrope* or *Bloodstone*. A faintly translucent leek-green variety, resembling jasper, is called *Plasma*. It presents conchoidal fracture.

Chalcedony is not unfrequently stalactitic, and is occasionally formed in cavities. These specimens often attain very large size. *Chert* seems to be a sort of granular chalcedony and passes into the rock called *Hornstone*.

363. Flint. This is a massive compact silica, of dark shades of smoky grey, brown, or black. Its fracture is conchoidal; it forms into masses of various grotesque and irregular shapes, and is abundantly present embedded in chalk, often presenting the structure of soft, spongiform, and other marine animals.

It is less transparent than any of the varieties of agate, and is connected with them by chert, fragments being sometimes found which present both forms in a hard specimen. There is a variety of flint occasionally met with in a spongy or cellular form, the cavities being themselves subsequently filled with quartz, forming a stone adapted for grinding. This kind of mill-stone differs from the coarse granular sandstone used generally for the same purpose in England.

Float-stone is a name given to a fibrous spongy variety of quartz so light as to float in water. *Tabular-quartz* is another form, also cellular, but consisting of plates either parallel to or crossing one another.

364. Earthy Quartz.—This sub-species consists of a powdery mineral, often found on the surface of flint, or produced by infusorial ancimalules, or else deposited by thermal springs as a siliceous incrustation on organic bodies. The well-known polishing powder of Bilin, in Bohemia, and common *Tripoli*, is of this kind. *Gelatinous silex* (*Randanite*) is a remarkable variety, and *Malthacite* and *Michaelite* are Hydrates of silica, probably belonging to this group. *Adhesive-slate*, *Polishing-slate*, are other varieties.

365. Jasper. The minerals to which this name is given are merely varieties of quartz coloured by iron, of which they contain 2·75—4· per cent. They are quite opaque, often present zones or bands like agates, admit of high polish, and are of some value. Next to the valuable and ornamental specimens, those called *Lydian stone*, *Basanite*, or *Touchstone*, are the most important, being of a velvet black colour (produced by carbon), and used on account of their hardness as a test on which to determine the purity of the precious metals, the half-polished surface acting as a fine file, and the blackness of the mineral showing the colour of the metal.

366. Opal ($H=5{\cdot}5-6{\cdot}5$, $SG=2-2{\cdot}2$). Opal may almost be regarded as a distinct species, presenting always a per centage of water, which, however, varies from little more than two to more than thirteen parts in a hundred, together with (generally) some oxide of iron, and a small quantity of the alkaline earths. It is compact and amorphous, and sometimes stalactitic, of very variable colour, and often with a play of colours of great brilliancy; of hardness inferior to pure quartz, and of comparatively low specific gravity. The following are the most remarkable varieties.

1. *Precious-opal*, *Noble-opal*, A valuable gem, the largest known specimen of which weighs 17 ounces, and is as large as a man's fist. External colour milky, with rich play of delicate tints.

2. *Fire-opal, Girasol*, Yellow with bright hyacinth or fire-red reflections.

3. *Common-opal, Semiopal,* has milky opalescence, but no true play of colours.

4. *Hydrophane.* Opaque, white, or yellowish when dry, but translucent and opalescent when immersed in water. It is strongly adherent to the tongue.

5. *Cacholong,* resembles chalcedony, but contains water and also a little alumina.

6. *Hyalite, Müller's-glass, Fiorite,* a glassy transparent variety resembling very transparent gum-arabic ; occurs in small concretions, stalactitic and stalagmitic.

7. *Menilite,* a brown opaque variety, not unfrequently slaty, found in kidney-shaped masses at Mont Menil, near Paris.

8. *Wood-opal,* impure, resembling wood, and consisting of wood petrified with opal.

9. *Opal-jasper,* resembles jasper and contains iron.

10. *Tabasheer,* a siliceous aggregation found in the joints of the bamboo.

11. *Siliceous-sinter* has sometimes an opaline character, and is deposited from hot springs and near volcanoes.

SULPHUR.

367. Sulphur (Prismatic, H=2·3, SG=1·9–2·1) occurs native in acute octahedral crystals, and massive. Colour and streak a peculiar and well known yellow; lustre resinous; very brittle; transparent or translucent on the edges. It is common in volcanic districts, often in an efflorescent form, and in fine powder. Large quantities are obtained in this way from Vesuvius, and are used in the manufacture of gunpowder, for bleaching, in the manufacture of sulphuric acid, and also in medicines. It is often deposited from springs.

The trade in native sulphur is not unimportant. In 1844, about 66,000 tons were exported from Sicily ; and in 1845, more than 40,000 tons, of which quantity nearly one half is brought to England.

SELENIUM.

ARSENIC (§ 477).

PHOSPHORUS.

368. Sulphur, Selenium, and Arsenic, have very close relations with each other, the two former minerals especially, but the latter, as well as Tellurium and Osmium, which likewise have chemical relations with sulphur, are more conveniently considered as metals. Selenium and Arsenic form compounds called *Seleniurets* and *Arseniurets*. Sulphur forms *Sulphurets* of various metals; these compounds being at once determined by the odour given off when heat is applied. The odour of sulphur and also of burning sulphur, are well-known ; that of selenium resembles horse-radish ; and that of arsenic, garlic. Selenium is found native and also in combination with sulphur and arsenic in Selen-sulphur. Arsenic and its combinations will be described amongst the metals. Phosphorus is chiefly known in its combinations, either directly as in *Phosphurets,* or in the form of phosphoric acid, in the phosphates of various metals and other bases.

The following elements belong in strictness to the present class, but are more conveniently considered under the class of metals. A reference is given to the paragraph where they are described.

TITANIUM (§ 482).	TELLURIUM (§ 473).	CHROMIUM (§ 461).
TANTALUM (§ 483).	MERCURY (§ 480).	OSMIUM (§ 514).
VANADIUM (§ 495).	MOLYBDENUM (§ 494).	RHODIUM (§ 515).
ANTIMONY (§ 475.)	TUNGSTEN (§ 493).	

CLASS THE SECOND.

ALKALINE SALTS.

The minerals belonging to this class are soluble in water, and have a distinct taste.

Salts of Ammonia.

369. SAL AMMONIAC, *Sal volatile, Salmiac, Hartshorn,* Muriate of ammonia, (Octahedral, H=1·5—2, SG=1·528.) Found crusted and efflorescent, and sometimes crystalline, the usual form being a regular octahedron. Occurs in many volcanic districts, and about ignited coal seams; soon decomposes, and is volatile at a low temperature; colour white, yellowish, or grey; soluble in three parts of water. Used in medicine, in dyeing, by tin workers in soldering, and mixed with iron filings, or turnings, to pack joints in steam apparatus. Obtained artificially.

MASCAGNINE, Sulphate of ammonia with water. (H=2—2·5, SG=1·7—1·8.)

GUANITE, Phosphate of ammonia and magnesia.

STRUVITE, Phosphate of ammonia and magnesia, with water. This mineral and the preceding are only doubtfully referred to the mineral kingdom.

Salts of Potash.

370. NITRE, *Saltpetre,* Nitrate of potash, (Rhombohedral. Isomorphous with Arragonite, H=2, SG=1·93.) In white subtransparent crusts and acicular crystals; colour, white; translucent. Soluble in three parts of cold, or two parts of hot water. Is widely distributed especially in Spain and Egypt, and is abundant, being derived from the decomposition of various rocks. Used in the manufacture of gunpowder and fireworks, and of nitric and sulphuric acids, in medicine, and in glass-working.

SULPHATE OF POTASH.

SYLVINE, Chloride of potash (SG = 1·9—2). This and the preceding salt have been found native.

ALUM, a double salt of alumina and potash, is described among the salts of alumina (§ 398).

Salts of Soda.

371. ROCK SALT, Chloride of sodium, (Octahedral, NaCl, H=2, SG =2·257.) Occurs in cubes and derived forms, also in masses more or less laminated, and associated with gypsum, and in fibrous masses. It is a chloride of sodium, generally with some impurities. It is soluble in nearly three times its weight of water and decrepitates on charcoal. Colour of crystals when pure, white, greyish, rose-red, yellow, and amethystine. Sometimes massive.

Very abundant in certain districts: it occurs in thick beds and masses in the New red sandstone of Cheshire in England, at Cardova

in Spain, Wieliczka in Poland, Halle in the Tyrol, Bex in Switzerland, and in various places in Hungary.

NITRATINE, Nitrate of soda (Hexagonal, isomorphous with Dolomite. H=1·5—2, SG=2·1—2·2). Abundant in South America. Used in the manufacture of aquafortis.

NATRON, Carbonate of soda (Monoclinic, H=1—1·5, SG=1·4—1·5). Used in manufacture of soap, in smelting silver, in dyeing and bleaching, and for medicine.

TRONA, *Urao*, Hydrous sesqui-carbonate of soda (Monoclinic, H=2·5—3, SG=2·1—2·2).

GAY-LUSSITE, Hydrous bi-carbonate of soda and lime (Monoclinic, H=2·5, SG=1·9—1·95).

GLAUBER-SALTS, *Blœdite*, *Russite*, Hydrous sulphate of soda (Monoclinic, H=1·5—2, SG=1·4—1·5). Used in medicine.

THENARDITE, Anhydrous sulphate of soda.

GLAUBERITE, *Brongnartine*, *Polyhalite?* Sulphate of soda and lime.

MARTINSITE, Chloride of sodium and sulphate of magnesia.

372. BORAX, *Tincal*, Hydrous borate of soda (Monoclinic, H=2—2·5, SG=1·716). In white transparent crystals with glassy lustre. Taste, sweetish alkaline; swells, and becomes opaque white before the blowpipe, and fuses. Is soluble in twelve times its weight of cold, and six times its weight of hot water. Formerly obtained chiefly from Thibet, but now from Tuscany. Used as a flux in various metallurgical operations, in soldering, and in the manufacture of imitative gems.

CLASS THE THIRD.

ALKALINE EARTHS AND EARTHS.

373. All the minerals of this class are stony; when pure they are colourless, or milk-white. Usually (with the exception of Corundum) not hard enough to scratch glass. Specific gravity, except in the case of Tungstate of lime, between 2·5 and 4·6; generally infusible before the blowpipe.

Salts of Barytes.

374. WITHERITE, *Barolite*, Carbonate of Barytes, (Prismatic, H=3—3·5, SG=4·3.) Remarkable for its high specific gravity; occurs generally in six-sided prisms, or modified rhombic prisms, very imperfectly cleavable; and also in globular and botryoidal masses, showing prismatic structure. Brittle. Decrepitates before the blowpipe, fusing easily to a transparent globule, which becomes opaque on cooling. Effervesces in nitric acid. It is chiefly abundant at Alston Moor in Cumberland, and Anglezark in Lancashire, and also in Styria. It is used to obtain the salts of barytes, much used in chemical analysis, and also in pyrotechny, and in the manufacture of colour for artists; it is poisonous. *Sulphato-carbonate of barytes* is a variety of this mineral containing sulphate of barytes.

BARYTO-CALCITE, *Bromlite*, Carbonate of lime and barytes.

375. HEAVY-SPAR, *Hepatite, Bologna spar*, Sulphate of Barytes, (Prismatic, H=3—3·5, SG=4·3—4·7.) This mineral is presented in various forms, viz., crystalline, fibrous, saccharoid, compact, and earthy. Its high specific gravity distinguishes it from most minerals. Some varieties are fetid when rubbed, others phosphorescent when heated. It decrepitates before the blow-pipe, and fuses with difficulty. It does not effervesce with acids, and exhibits no metallic reactions before the blowpipe ; colour white, inclining to yellow, grey, blue, red, or brown ; streak white. It is generally associated with ores of metals, especially lead. It is used sometimes instead of white lead, either openly, or in adulterating the latter mineral, but mixed with white lead it forms the pigments called *Venice white, Hamburgh white, and Dutch white*, according to the proportions. *Bologna spar* is highly phosphorescent after calcination. *Allomorphite* is identical ; *Cawk* is a massive variety.

DREELITE. Sulphate of barytes and lime.

Salts of Strontia.

376. STRONTIANITE, Carbonate of strontia (Prismatic, H=3·5, SG=3·6—3·8), occurs in modified rhombic prisms, with nearly perfect cleavage ; also in fibrous and granular masses, sometimes globular, with internal radiated structure. Colour usually light green, white, grey, and yellowish-brown ; brittle, transparent, or translucent ; vitreous lustre. Fuses before the blowpipe tinging the flame red. Found with galena at Strontian, in Argyleshire, N.B., whence the name. Used in the preparation of nitrate of strontia, which is extensively employed in giving a red colour to fireworks. *Emmonite* and *Stromnite* are varieties, the latter is sometimes called *Barystrontianite*.

377. CELESTINE, Sulphate of strontia. (Rhombohedral, H=3—3·5, SG=3·9—4.) Crystallised in modified rhombic prisms, sometimes flattened, often long and slender, with distinct cleavage. Also massive, laminated, columnar and fibrous—rarely granular. Transparent or translucent ; colour blue or white ; lustre pearly or vitreous. Phosphorescent when heated. Very brittle. Found abundantly in Sicily with Sulphur and Gypsum, and frequently mixed with sulphates of lime and barytes, forming *Calcareo-sulphate of strontian, Baryto-sulphate of strontian, Calcite* and *Natrocalcite*. *Baryto-celestine* is a variety.

Salts of Lime.

378. CALC-SPAR (CaC_2, Hexagonal, H=3, SG=2·5—2·8). This very important mineral, remarkable for the varieties of form in which it is presented, may be best described under the following

subdivisions, all of which have the same chemical composition when pure, although they are greatly modified in appearance. All effervesce freely with the mineral acids, and all under the blow-pipe are reduced to quick-lime. All are easily scratched with a common knife. Calc-spar is one of the two dimorphic forms of Carbonate of lime; the other form is called Arragonite, and will be described separately.

1. Crystalline carbonate of lime.
2. Fibrous ditto.
3. Saccharoid ditto.
4. Compact ditto.
5. Earthy ditto.

379. Crystalline Varieties.—*Iceland-spar* includes the most perfect and distinct crystals, and these are transparent with vitreous lustre, doubly refractive in a high degree, and generally rhombohedrons. *Calc-spar*, or *Calcite*, is a name given to similar crystals when opaque; they are often white or pinkish. One variety of the fundamental rhombohedron is called *Nail-head spar*, and a common dodecahedron is *Dog-tooth-spar*. Many other forms also occur. The vast variety of forms into which this mineral passes, renders it difficult to describe at least, in crystallography, but in other respects it is very easily recognised. The cleavage is perfect, and all varieties are brittle. The crystals sometimes attain gigantic dimensions.

Argentine is a white laminated limestone containing a small portion of silica, and *Nacreous carbonate of lime*, *Madreporite*, *Schiefer* or *slate spar*, and *Aphrite*, *Schaum-erde*, or *Earth-foam* belong to the group which we are now considering. *Plumbo-calcite* is a calc spar containing a certain per centage of carbonate of lead. *Fontainebleau sandstone* is an impure pseudomorphous variety of carbonate of lime.

380. Fibrous Varieties.—Of these, *Satin-spar* is the most common, and specimens of it, worked by the Egyptians, are sometimes called Alabaster. The fibrous varieties chiefly occur in veins traversing rocks of different kinds, but are also presented in the well-known *Stalactites* and *Stalagmites*, concretions found in caverns in limestone rocks.

381. Marbles.—Under this head are included all the semi-transparent, semi-crystalline, or crystalline forms of carbonates of lime to which the name *marble* is applied. The finest kinds for statuary purposes, from Carrara, are of a pure white, and from Paros, of a waxy cream colour; others are mixed with various metallic oxides, occurring in veins, and producing clouded and coloured varieties, used for various ornamental purposes. *Giallo-antico* is yellow and mixed with a small proportion of hydrate of iron, *Rosso-antico*, a deep blood-red; *Mandelato*, a light red; and *Verd-antique*, a cloudy green variety mixed with serpentine. *Cipolino*, is a mixture of talcose schist with white saccharoidal marble. The *Black-marble* of Derbyshire presents a combination of carbonate of lime and bitumen, and like some of the other marbles of that part of England, made up entirely of coralline or encrinital remains or shells, belongs rather to the next group.

382. Compact Varieties.—The carbonates of lime of this group are extremely abundant in quantity, and present very great modifications. They form thick deposits of various geological dates; are presented in association with various proportions of argillaceous earth, of silex, of oxide of iron, and of carbon; are of various colours and various degrees of hardness, and exhibit great varieties of texture. The following are important varieties:—

1. *Hydraulic-limestone*, the per-centage of argillaceous earth being 10 to 12 in moderately good samples, 15 in ordinary sorts, 16 in good, and 20 to 30 in those which are eminently adapted for making hydraulic cement.

2. *Cement-stone.*—A name given to compounds where the proportion of argillaceous earth is still greater than in the former case. Thus the stone from which Roman-

cement is made in England contains 36 per cent. of clay and 8·60 per cent. of oxide of iron. They are at once recognised by the argillaceous odour they emit when breathed on. They frequently form lumps or nodules in clay. *Stinkstone*, or *Anthraconite*, is a bituminous variety, giving off a fetid odour when struck.

3. *Oolite* is a small-grained, and *Pisolite* a large-grained, compact stone, formed of carbonate of lime, and consisting of concentric layers collected round a central point, usually organic, and cemented by a calcareous cement.

4. *Lumachelle*, or *Fire-marble*, is a dark brown variety having brilliant chatoyant reflections.

5. Uncrystalline, or rather semi-crystalline marbles, of which there are many kinds, form another group, some of uniform texture and of various colours, others veined, others more or less fossiliferous. The *Purbeck* and *Petworth marbles*, *Forest-marble*, &c., are English examples.

383. Earthy Varieties.—Of these there are also several. *Chalk* is, perhaps, the most abundant, and consists of nearly pure carbonate of lime in a peculiar mechanical condition. *Rock-milk*, or *Agaric-mineral*, and *Mountain-meal*, resemble chalk, but are still more earthy. *Calcareous tufa*, and the *Calcaire grossier*, of Paris, are other examples. *Marl* is an earthy carbonate of lime with a large per-centage (40 to 50 per cent.) of clay. *Stalactites* and *Stalagmites*, the incrustations found in caverns, are also sometimes earthy. A large number of limestones must be regarded as rocks rather than simple minerals, and will be described in a future chapter.

384. Arragonite, *Prismatic carbonate of lime, Iglöite, Flos-ferri.* (Prismatic, H = 3·5 – 4, SG = 2·93.) A remarkable dimorphic form of carbonate of lime, crystallising often in hexagonal prisms or stellated forms, and appearing in fibrous seams and in globular coralloid masses. Its colour is white, with tints of grey, yellow, green, and violet. It is transparent or translucent. Found associated with gypsum and iron ore beds. It is not employed for any purpose in the arts.

385. Dolomite. *Pearl-spar, Miémite, Bitter-spar, Garofian, Tharandite, Brown-spar, Rhomb-spar.* (Hexagonal, H = 3·5 – 4·5, SG = 2·8 – 2·95.) A compound of carbonate of magnesia with carbonate of lime ($CaC_2 + MgC_2$); infusible before the blowpipe; effervescing slowly with acids; colour generally yellowish or creamy; lustre pearly; brittle; translucent. It burns to lime like common limestone, and makes a stronger cement. It is used in the manufacture of Epsom salts. As *Magnesian limestone* it forms extensive and widely spread deposits in various districts, some of them producing excellent building material.

The *Blue-limestone*, or *Blue Lava, of Vesuvius*, is really a dolomite, and belongs therefore to this group. *Predazzite* is, probably, a variety.

386. Fluor-spar, *Chlorophane*, Fluate of lime (Octahedral, H = 4, G = 3·1 – 3·2). Called by miners *Blue John*. Generally found in tolerably perfect cubes, or compact. Transparent or translucent, exhibiting much variety of colour, generally shades of yellow, blue, or green. Many varieties are phosphorescent when heated. Used for ornamental purposes, and in the manufacture of fluoric acid. It abounds in the lead-mines of Derbyshire, Cornwall, and elsewhere. *Ratofkite* is fluor-spar with sulphate of barytes.

387. Gypsum, *Alabaster, Satin-spar, Selenite,* Hydrous Sulphate of lime (Monoclinic, H=1·5–2, SG=2·264–2·35). Like carbonate of lime and dolomite, this mineral, which is very abundant, presents itself in several forms, being found crystalline or lamellar, fibrous, saccharoid, and compact. It consists of $CaS_3 + 2$ Aq. The plates, of which laminated varieties are formed, bend in one direction, but are brittle in another. It is eminently foliated in one direction. It parts with its water, and is whitened on calcination, becoming, when ground, *Plaster of Paris,* a substance which is well known, and which becomes solid on admixture with a certain quantity of water.

The more remarkable varieties are *Alabaster* or snowy gypsum, *Fibrous* or *Plumose gypsum* and *Satin-spar,* and radiated gypsum. When crystalline, it is often quite transparent, and is generally colourless, or lightly tinted. It shows no action with acids. Used, as above-mentioned, in the manufacture of Plaster of Paris, and also for various ornamental purposes, chiefly as Alabaster.

388. Anhydrite, *Muriacite, Vulpinite,* Anhydrous sulphate of lime (Prismatic, H=3–3·5, SG=2·8–3). The name *Anhydrite* is given to crystalline anhydrous sulphate of lime, and *Vulpinite* to a mixture of the same salt with a little silex. The latter mineral takes a high polish, and is used for ornamental purposes, being harder than the other varieties. Anhydrite is generally somewhat harder than statuary marble, and presents no whitening or exfoliation before the blow-pipe.

389. Apatite, *Phosphorite, Asparagus Stone, Moroxite* (Hexagonal, H=5, SG=3·166–3·285). Phosphate of lime with chloride or fluoride of calcium. Occurs generally crystalline. Soluble in nitric acid; fusible with difficulty. Its powder is phosphorescent. It is found in various districts in a granular, compact, concretionary, or earthy form, and frequently in old rocks. It has been attempted, but not successfully, to make use of the Phosphorite of Estremadura (where it is very abundant) for agricultural purposes.

390. The following phosphates, arseniates, and other salts of lime, are of little general interest.

Pharmacolite, Hydrous Arsenate of lime. *Haidingerite* is a variety containing a larger per-centage of water, and *Picropharmacolite,* a supposed sub-arsenate, containing magnesia. Both are referred, by Dufrénoy, to this species; *Roselite* is, probably, another variety.

Berzelite, Anhydrous sub-arsenate of lime with magnesia.

Romeine, Antimonate of lime.

Perowskite, Titanate of lime.

Pyrochlore, Titanate of lime, uranium, cerium and iron.

Scheelite, *White wolfram, White tungsten,* Tungstate of lime.

Nitrate of lime.

Muriate of lime.

Hayesine, Hydrous borate of lime.

Oxalate of lime.

Salts of Magnesia.

PERICLASE, Native magnesia.

BRUCITE, Hydrate of magnesia.

NEMALITE, Hydrous carbonate of magnesia.

BREUNERITE, Carbonate of magnesia.

391. MAGNESITE, or *Meerschaum* (H=2—2·5, SG=0·8—1·0), is an earthy and siliceous carbonate of magnesia, often confounded with the true carbonate, which is much more rare. It resembles chalk, but is harsher. It gives off water on calcination, and does not effervesce with acids when pure.

Aphrodite, *Dermatine*, and *Quincite*, are varieties; the first-named nearly pure, but much heavier than magnesite (SG=2·21); the second contains iron and manganese, and the last a large per-centage of silica. The mineral is used in the manufacture of pipes, and obtained chiefly from the Crimea and from near Konie, in Natolia. The name *Magnesite* is sometimes given to a compact and pure carbonate, whose specific gravity is 2·85—2·95.

BORACITE, *Rhodizite*, Borate of magnesia.

HYDROBORACITE, Hydrous borate of magnesia with lime.

WAGNERITE, Phosphate of magnesia.

392. EPSOM SALTS, *Epsomite*, Sulphate of magnesia (Prismatic, H=2—2·5, SG=1·7—1·8). Found occasionally in caverns and in mineral springs. Used in medicine. Obtained artificially from dolomite. *Astrakanite* and *Reussin* are varieties.

NITRATE OF MAGNESIA.

MURIATE OF MAGNESIA.

Salts of Yttria.

393. The following are of little importance. They contain, besides yttria, other rare earths and metals, especially cerium, zirconium, uranium, lanthanum, tantalum, &c. See § 444.

PHOSPHATE OF YTTRIA, *Xenotime*, *Thorite*.

YTTROCERITE, Fluate of yttria, cerium, and calcium.

YTTROTANTALITE, Black, yellow, and brown varieties, consisting of compound Tantalates of yttria and lime with uranium, and, in some cases, cerium, and lanthanum, combined, also, with Tungstates of iron, uranium, &c. *Euxinite* is identified with the brown Yttrotantalate.

FERGUSONITE, Tantalate of yttria and zirconium.

GADOLINITE, Silicate of yttria, cerium and iron, with glucina.

Salts of Alumina.

394. CORUNDUM (Hexagonal, isomorphous with peroxide of iron and chrome, Al_2O_3, H=9, SG=3·9—4·16). The minerals collected together under this name, and consisting essentially of pure crystalline alumina coloured by iron or other metallic oxides, differ enormously in colour, appearance, and value. There are two principal groups, one crystalline and the other granular; each of which requires some notice. All specimens agree in possessing extreme hardness, inferior only to the diamond, and this gives great value to the granular varieties, which would otherwise be worthless. The specific gravity is high. All are infusible under the blow-pipe, and

totally unchanged by acids. The different varieties that have been analysed give from 84 to 98 per cent. of alumina, with a variable proportion of oxide of iron and silica.

1. Crystalline Varieties.—These are generally transparent, and coloured blue or red; the former most frequently; the colour is often confined to the edges of the crystal. The crystalline form usually six-sided prisms, but often not traceable. The fine azure or indigo-blue varieties are called *Sapphire;* the red, *Oriental ruby;* the yellow, *Oriental topaz;* the green, *Oriental emerald;* and the violet, *Oriental amethyst.* Of these, the ruby is the most valuable, and fine stones often exceed the diamond in value. The best crystalline corundums are obtained from the kingdom of Ava and from Ceylon. The largest known ruby is in the crown of Russia. Imperfect opaque laminated masses exhibiting distinct cleavage are found in Ceylon and elsewhere, and have been called *Compact corundum.* Corundum, is the name given, generally, to rough, opaque, dull masses.

2. Granular Varieties.—These are better known by the name of *Emery.* They are impure, and occur in boulders, or nodules, in gneissoid, mica-slate, or talcose rock, and even in granular limestone, associated with oxide of iron. The colour is smoke-grey or bluish-grey; fracture imperfect. The use of this mineral is chiefly confined to cutting and polishing gems and other very hard substances. The best kinds are those having a blue tint; but many substances are sold under the name of emery which contain no corundum. Emery is chiefly brought from Naxos, Smyrna, and other Greek islands, and from Spain, Saxony, Greenland, and the East Indies.

395. We have next a small group of Hydrates of alumina of little importance.

Gibbsite, a Hydrate of alumina (Al+Aq, H=3—3·5, SG=2·4). Earthy, greenish colour, and resembles chalcedony. Contains alumina 64·8, water 35·7.

Hydrargylite, another Hydrate of alumina, probably containing two parts of alumina to one of water ($2Al+Aq$). *Claussenite* is a variety.

Diaspore, a third Hydrate of Alumina ($3\,Al$+Aq). A variety of this mineral from Chemnitz exhibits dichroism.

396. Wavellite. Hydrous phosphate of alumina, probably with fluate of alumina. (Hexagonal, H = 3·5 — 4, SG=2·33—2·37.) A fibrous, pale-green, or yellowish mineral, usually in small hemispheres, attached to fissures in aluminous rocks. Translucent. Common at Barnstaple in Devonshire. Of no value. *Fischerite* and *Peganite* from the Ural are, perhaps, distinct, but may for the present be included either with Wavellite or Turquoise. A supposed *Plumbiferous phosphate of alumina* has been described, and also a mineral called *Childrenite,* supposed to contain phosphoric acid, alumina, and iron.

Ambligonite, Phosphate of alumina and lithia.

Lazulite, *Klaprothrine*, Double phosphate of alumina and magnesia.

397. Turquoise. *Calaite, Agaphite, Johnite.* Phosphate of alumina with copper and iron. (H = 6, SG=2·62—3.) A well-known mineral, used for ornamental purposes, having a bluish green colour, nearly opaque, and of somewhat waxy lustre. Hardness a little greater than Apatite. The blue colour is lost by the action of muriatic acid. The considerable value of this amorphous gem has induced imitations, which are now very common, but they are gene-

rally much softer than the true mineral. *Variscite* is also a phosphate of alumina, of a green colour.

FLUELITE, Fluoride of alumina.

CRYOLITE, *Ice-stone*, is a Fluoride of alumina and sodium, and *Chiolite* is nearly allied.

398. We have now a small group of Sulphates of alumina of some interest.

FEATHER-ALUM, Hydrous sulphate of alumina, common in solfataras, in mines, and generally where argillaceous rocks are exposed to the action of decomposed sulphurets.

WEBSTERITE, *Aluminite*, Hydrous sub-sulphate of alumina, found in compact reniform masses and beds, at Halle in Saxony, and Newhaven in Sussex. Of white colour and earthy appearance.

ALUM STONE. *Alunite*. Hydrous sub-sulphate of alumina and potash. (Hexagonal, H=3·5–4, SG=2·6–2·8.) Abundant at Tolfa near Rome, in Hungary, and elsewhere, and much used formerly in the manufacture of common alum, to which it very closely approximates. Found in crystals with perfect cleavage, and also massive. Pearly; translucent. Alum is chiefly obtained now from the decomposition of certain shales.

NATIVE ALUM.—This is also a hydrous sub-sulphate of alumina and potash, the proportion of water being larger than in alum-stone. *Ammonia-alum*, *Soda-alum*, *Magnesia-alum*, *Iron-alum*, and *Manganese-alum*, are isomorphic varieties in which ammonia, soda, magnesia, iron, or manganese, replace the potash. The minerals called *Davyte*, *Pissophane*, and *Pickeringite*, are varieties of the same kind.

The three minerals, alum, alum-stone, and aluminite are often confounded. The following analyses of them may, therefore, be useful:—

	Alum.	Alumstone.	Aluminite.
Alumina	10·8	31·8	29·8
Potass	10·1	5·8	
Sulphuric acid	33·7	27·0	23·3
Water	45·4	33·7	46·7
	100·0	98·3	99·8

MELLITE, Hydrous mellite of alumina, is a resinous substance found on bituminous wood, in Thuringia, and sometimes regarded as a resin. It is probably of organic origin, or at least derived from organic sources.

CLASS THE FOURTH.

SILICATES.

399. The minerals of this class are stony. Their specific gravity ranges from 2·5 to 4, rarely approaching the latter. They are generally crystalline, and rarely quite amorphous, except, indeed, in the case of the hydro-silicates of alumina. They form two distinct groups, the hydrous and anhydrous silicates; the first soft, and readily soluble in acids, the second hard, and either insoluble in acids, or only soluble with difficulty. Few of them are of great use in the arts, and those chiefly as ornaments and for jewellery.

Anhydrous Aluminous Silicates.

400. CYANITE. *Disthene, Sapparite.* (Monoclinic, H=5–7, SG =3·56–3·7.) Silicate of alumina. It is an abundant mineral. Usually found in long thin-bladed crystals, of light blue colour and pearly lustre, with distinct lateral cleavage; rather brittle, infusible, and without a flux, only losing its colour before the blow-pipe. White varieties are called *Rhœtizite*, and fibrous specimens *Fibrolite*. *Bucholzite* is an analogous mineral, also fibrous. *Sillimanite* is a variety occurring in rhombic prisms, with brilliant and easy cleavage. *Wörthite* resembles Cyanite, but contains water. (See § 397.)

ANDALUSITE—(Hexagonal, H=7—7·5, SG=3·1—3·3). A silicate of alumina and probably a form of Cyanite, which is in that case dimorphous. This mineral occurs in right rhombic prisms, massive, coarse, columnar, but never fine-fibrous. Colour flesh-red and grey; lustre, vitreous or pearly; tough; translucent to opaque.

Tesselated and cruciform crystals of Andalusite are common, and present several varieties. *Steinmark* is a compact variety. Both Cyanite and Andalusite often contain iron.

STAUROLITE, *Chiastolite*, *Cross-stone*, *Staurotide*. (Hexagonal, H=6·75, SG=3·3—3·7.) Silicate of alumina and iron. Colour grey, reddish-brown, or dark brown. Occurs, generally, in micaceous schists and gneiss. It is very abundant, and generally cruciform, two crystals crossing each other. (See § 287.) *Chiastolite* is common in some slate rocks.

Hydrous Aluminous Silicates.

401. Almost all the minerals included in this group are badly defined and doubtful, few of them occurring crystalline or with permanent well marked character.

FAHLUNITE, *Triklasite*, Hydrous silicate of alumina with magnesia, oxide of iron, and oxide of manganese. *Pyrargillite* is a variety. The following are, also, hydrous silicates of alumina—*Pholerite*, *Hydrobucholzite*, *Wörthite*, *Gilbertite*, *Kosite*, *Gröppite*, and *Smelite*. They are generally soft and earthy, often resembling clays and magnesian earths, from which they are, however, distinguishable by becoming milk-white before the blow-pipe, and refusing to fuse. They are none of them of any known use.

402. CLAY. Under this name may be included a multitude of earthy minerals, whose base is hydrous silicate of alumina, but which present admixtures of iron, manganese, lime, magnesia, potash and soda, with free silica. The proportions of silica, alumina, and water are variable, and thus the different varieties may be collected into groups. They are all amorphous, and many of them very useful in various plastic arts.

Clays proper. The clays of this group contain only from 10 to 12 per cent. of water. They resist the action of acids, and form into a tenacious paste with water. They are much used in the fabrication of china and pottery, and include several distinct varieties.

1. *Kaolin* or *Porcelain-clay*, the material used in the manufacture of the finer kinds of porcelain, and derived generally from granitic rocks, and from the decomposition of felspar. It is of loose earthy texture, SG=2·21 to 2·26. Different localities give

clay of this kind containing from 17½ to 47½ per cent. of silica, 15 to 44 per cent. of alumina, 5 to 15 per cent. of water, a proportion varying from a mere trace to 6 per cent. of alkaline earths, with traces of iron and manganese, and from less than one to more than 12 per cent. of sand or free silica.

2. *Plastic-clay*, or *Potter's-clay*, used for the less valuable and costly kinds of pottery. The varieties thus designated are far more soapy and plastic than the former, absolutely infusible when pure, slightly soluble in acids, especially after moderate calcination, and parting with their water only at a red-heat. A specimen from Devonshire, of good quality, shows the following composition: Silica 49·60, alumina 37·40, water 11·20.

Lithomarge is a variety referable to this group.

3. *Brick-clay* or *loam*, contains a little lime, varying from 5 to 6 per cent., partly as carbonate and partly as silicate. Most clays of this kind contain iron.

4. *Marl* is the name given to combinations of clay with 20—25 per cent. of carbonate of lime.

5. *Ochres.*—These are generally mixtures of a large proportion of oxide of iron with clay; they are sometimes of uniform yellow or red tint, and sometimes variegated. *Plinthile* is a ferruginous clay, and so, also, is *Fettbole*.

6. *Bituminous clays*, containing a variable proportion of carbon. *Stourbridge clay* is of this kind, and is used in the manufacture of crucibles, and for other purposes where exposure to intense heat is required.

403. *Hydrated clays.* These contain a much larger proportion of water, and have in many cases distinct properties, but only one of them has any economic value.

7. *Fullers-earth*, a greenish or bluish earth containing about 25 per cent. of water, 50 per cent of silica, and 20 per cent of alumina. Soft, tenacious, and falling to pieces in water; generally of blue or green colour, SG=2·3—2·5. Fuses into a greenish grey glass before the blow-pipe. It was formerly much used in the fulling of cloth, and is still valuable for that purpose.

8. *Halloysite*, or *Halloylite*, a whitish opaline mineral becoming transparent in water, like hydrophane. (SG=2· to 2·2.) Fusible before the blow-pipe, unctuous and steatitic to the touch. The following minerals belong to this variety—*Tuesite*, *Lenzinite*, *Cymolite*, *Razoumoffskine*, *Mountain-soap*, *Alumocalcite*.

9. *Allophane* differs but little from Halloysite, but contains generally much more water. It is translucent, like wax. Its colour is pale blue and streak white. H=3, SG=1·85—1·90. It changes colour and becomes opaque before the blow-pipe, and tinges the flame green. Occurs reniform, massive, and sometimes earthy. *Schrötterite*, or *Opal Allophane*, is a variety.

10. *Kollyrite* is a Hydrous silicate of alumina, in which the proportion of silica is extremely small. It is white and translucent. *Erinite* is probably a variety, or, at least exhibits but little essential difference.

Silicates of Alumina and Lime, or their Isomorphs.

404. Garnet. (Octahedral, H=6·5—7·5, SG=3·5—4·3.) The large and interesting group of minerals collected under this name afford the best illustration of the theory of isomorphism. They present great differences of specific gravity, corresponding to differences of colour, and great complication in their chemical composition, but their form remains the same, and they may all be represented theoretically by the formula $B\,\dot{S}i + b\,\dot{S}i$, B representing bases which combine with 3 atoms of oxygen, and b other

bases, combining with only one. Thus some are *Al Si + Ca Si*, or Silicate of alumina and lime, or very nearly so; but it is so commonly the case that instead of alumina only, there is alumina and iron, or iron only, and the replacement is so variable, that no line can be drawn between this mineral and a Silicate of iron and lime (*Fe Si + Ca Si*), and all the apparent species, however strongly marked, thus pass into each other. It is, however, found convenient to collect the whole series into four groups, which are called respectively *Grossulare, Almandine, Melanite*, and *Spessartine*. The general crystalline form is the dodecahedron and its modifications; but massive specimens are common. The fracture is conchoidal, and there is a tolerably distinct cleavage parallel to the faces of the dodecahedron. The prevalent colour is red. Crystals transparent to opaque; lustre vitreous; brittle. They are generally fusible before the blow-pipe.

405. The following are the chief varieties:—

GROSSULAR VARIETIES.—These are silicates of alumina and lime; they include *Grossularite* in greenish crystals; *Essonite* or *Cinnamon-stone*, of light cinnamon yellow colour, and high lustre; *Erlan*, *Wilnite*, *Aplome*, a deep brown or orange variety; *Romanzovite*, *Topazolite*, a yellow variety; *Colophonite*, a coarse granular resinous variety; and *Succinite*, also a granular garnet.

ALMANDINE VARIETIES. — Silicates of alumina and iron; violet, red, brown, or black colour: hard; heavier than the former group. It includes the *Almandine* or *Precious garnet*, the mineral commonly used in jewellery under the name of garnet; a magnesian garnet, in which magnesia replaces the iron; and the *Pyrope*, or Bohemian garnet, also magnesian, but where a part of the alumina is replaced by oxide of chrome.

MELANITE VARIETIES.—In these, the alumina is replaced by peroxide of iron, and they are, therefore, silicates of iron and lime. *Melanite*, *Rothoffite*, *Pyreneite*, and *Allochroite*, are the principal forms, the latter still referable to the garnets, though possessing a certain quantity of free silica.

MANGANESIAN VARIETIES. — *Spessartine* is the name given to a deep red garnet in which protoxide of manganese replaces the lime of the usual formula, so that it becomes silicate of alumina and manganese. *Ouwarovite* is a fine emerald coloured form in which oxide of chromium replaces the alumina. Compact garnets of this kind have been found.

406. IDOCRASE (Square Prismatic, H=6·5, SG=3·35—4). A brown, green or blue, subtransparent species, generally presented in modified square prisms, and including the minerals *Vesuvian*, *Egeran*, *Cyprine* and *Frugardite*, as well as *Idocrase*. *Protheite* is a variety, and so also is *Xanthite*. All are silicates of alumina and lime with iron.

407. EPIDOTE (Monoclinic, H=6—7, G=3·32—3·5). Another well known mineral assuming many forms, and described by several names. There are three prominent varieties:—*Thallite*, *Zoisite*, and *Manganesian Epidote*, determined chiefly by crystalline structure, but partly from the difference of colour, which in the first is fine pistachio green, in the second, greenish grey, and in the last violet. They are represented generally by the formula *2B Si* +

b Si, which shows their relations with garnet (see the description of that mineral). *Pistacite, Bucklandite, Thulite, Scorza, Violane, Withamite*, are either synonyms or varieties of Epidote.

408. Scapolite (Square Prismatic, H=5—5·5, SG=2·6—2·8). Under this name are included *Wernerite, Paranthine* and *Meionite*, together with *Nuttalite, Ekebergite, Gabronite, Barsowite, Bergmanite, Ottrelite, Palagonite* and *Scolexerose*. *Arktizite* and *Rapidolite* are also synonyms. The mineral thus designated is represented by the formula $(3Al\,Si + Ca\,Si)$. It is widely distributed in old crystalline rocks and some volcanic rocks, presenting many varieties of form and structure. *Amphodelite* is a mineral of a similar composition, except that a certain quantity of the lime is replaced by magnesia.

Gehlenite, *Stylobite*. Contains 35 per cent. of lime.

Margarite, *Pearl-mica*.

409. Iolite (Prismatic, H=7–7·5, SG=2 5—2·7). A remarkably glassy violet-coloured mineral, transparent, and presenting dichroism very distinctly, whence it has been called *Dichroite*. It is also called *Cordierite* and *Water sapphire*, the latter name being given by jewellers to a variety from Ceylon, which presents different colours in two directions. Its formula is $3\,Al\,Si + (\mathrm{MgFe})\,Si_2$. *Steinheilite* is a synonym.

The following minerals, essentially silicates of alumina with another base, may be regarded as pseudomorphous varieties of iolite. *Bonsdorfite* or *Hydrous Iolite, Esmarkite, Praseolite*, or *Chlorophyllite, Fahlunite* or *Triclasite, Weissite, Pinite, Giesec-kite* or *Oosite, Gigantolite*.

410. Nephrite or *Jade*, also called *Axe-stone* and *Ceraunite* (H=6·5—7·5, SG=2·9 — 3·03). A hard, tough, and compact stone of greenish colour, without cleavage, lustre vitreous. It is a silicate of alumina and magnesia.

Sordawalite, Silicate of alumina and magnesia with phosphate of magnesia.

411. Emerald (Hexagonal, H=7·5–8, SG=2·6–2·8). Silicate of alumina and glucina. This mineral is sometimes perfectly transparent, and of a beautiful green colour, forming one of the rarest and most precious gems; more frequently it is semi-transparent, of sea-green colour, and often of large size. The less coloured specimens are called *Beryl* or *Aqua-marine*. Crystallises in hexagonal prisms. Beryls are often of large size, but seldom transparent. The name *Davidstonite* has been given to a supposed variety.

Euclase ($Al_2Si + 2GSi$, Monoclinic, H=7·5, SG=3·09). Cleavage very perfect; always crystalline; very brittle; electric by simple pressure; colour sea-green or blue; highly doubly-refracting; used sometimes as a gem, but rarely cuts well owing to its great brittleness.

Phenacite. Silicate of glucina.

Aluminous and Alkaline Silicates and their Isomorphs.

412. *Felspar group.*—Granites and many other unstratified rocks contain, as an important constituent part, a laminated nacreous mineral of white or pink colour and peculiar lustre called felspar. Generally this mineral is composed of silica, alumina, and potash, but this composition is by no means invariable, soda and other alkaline bases sometimes replacing the potash, the relative proportion of the ingredients varying, and modifications of the crystalline form being often observable. It has become necessary, as these variations from the original type have been studied, that the whole group of minerals, which with quartz and mica compose granitic rocks, and possess the external characters called felspathic, should be distinctly understood, for they do not all belong to the same crystalline system, and they possess important atomic differences, although their external characters are easily confused. Several ways have been suggested of bringing the subject into order, and the one here adopted is that given by M. Dufrénoy in his work on Mineralogy.

413. FELSPAR, or *Orthose,* also called *Adularia* and *Orthoclase* (Monoclinic, H$=$6, SG$=$2·39 $-$2·58), is the original species of the whole group, and must, therefore, be mentioned first. It is found crystalline, generally reddish-white, or flesh-coloured, and opaque; sometimes, as in *Amazon stone,* of a fine green. Fracture eminently lamellar. It becomes glassy white before the blow-pipe, and fuses with difficulty at the edge into a semi-transparent glass. Composition, Silicate of alumina and potash $(3Al\,Si_3 + K\,Si_3)$, but a portion of the potash is generally replaced by soda. A mineral named *Ryacolite* by G. Rose has been identified with felspar.

Laminated varieties sometimes present fine chatoyant lustre, as *Moon-stone.* Many felspathic rocks present earthy varieties of this form, and others compact felspar or *Petrosilex,* sometimes called *Fusible hornstone,* of which *Adinole* and *Leelite* are synonyms. A silky felspathic mineral is called *Necronite,* and some clear and brilliant crystals, *Ice-spar.*

Clink-stone or *Phonolite,* is a greyish variety of true felspar, frequently occurring in volcanic districts. *Pitchstone* or *Retinite* is a blackish, or bottle-green mineral, also volcanic; and *Obsidian* or *Volcanic-glass,* of which *Marekanite* is a variety, is also a well-known volcanic product. *Pumice* or *Volcanic-ash,* is a light spongy modification of obsidian; and *Murchisonite,* an interesting mineral from the New red sandstone of Exeter, is no doubt of the same origin although it exhibits a small excess of silica. The most interesting and most abundant forms of these and many other minerals will be alluded to again as rocks.

414. ALBITE (Triclinic, H$=$6$-$6·5, SG$=$2·6$-$2·7). In this species the potash of felspar is exactly replaced by soda, so that its formula is $(3Al\,Si^3 + Na\,Si^3)$. It includes *Pericline, Tetartine, Carnatite* and *Cleavelandite.* It is generally crystalline, but also massive and laminated. It resembles felspar in many respects, but is heavier. There are massive varieties, white and almost saccharoid, and sometimes fibrous. Some earthy Albites are also known,

whence soda-kaolin is derived. A peculiar soda-felspar is obtained from the Vosges and from Monte Rosa presenting some anomalies. *Loxoclase* is another variety from America.

415. LABRADORITE. *Labrador felspar, Opaline felspar* (Triclinic, H=6, SG=2·68—2·74). A felspar in which lime and soda together replace the potash. It is usually in cleavable massive forms, has nearly perfect cleavage, and presents a series of bright chatoyant colours, especially blue and green. It receives a high polish, and is sometimes used in jewellery. The name *Saussurite* has been given to a variety found in the Alps and called by De Saussure, *Jade*. *Chonikrite* is probably of the same kind. *Glaucolite* and *Silicite* are other varieties.

PETALITE, a felspathic mineral in which lithia takes the place of potash.

SPODUMENE or *Triphane*, another felspathic mineral, with a yet larger proportion of silicate of lithia in the place of silicate of potash.

OLIGOCLASE, *Soda-spodumene*, a mineral having the same relation to spodumene that albite has to true felspar. It occurs in the granites of Sweden and Norway, and also in the recent volcanic rock of Teneriffe. *Lime-oligoclase* has been found in Iceland.

ANORTHITE, *Biotine, Christianite, Indianite.* In this mineral, a certain proportion of magnesia, soda, and lime, replace a corresponding portion of the potash in felspar. With this species the list of felspathic minerals terminates.

416. LEUCITE. *Leucolite, Amphigene, Vesuvian garnet* (Octahedral, H=5·5—6, SG=2·4—2·5). Occurs in dull, glassy crystals, of the form of a trapezohedron of greyish colour. It is translucent and brittle. It is a silicate of alumina and potash, and is very abundant in the lava of Vesuvius.

Most of the following species are complicated combinations of various bases with silicate of alumina, and are of little general interest. Many of them are volcanic.

SODALITE, *Canorinite, Stroganowite.* Silicate of alumina and soda with chloride of soda.

NEPHELINE, *Beudantine, Davyne, Pinguite, Elæolite, Fat-stone.* Contains soda 15· potash 6· or carbonate of lime.

DIPYRE contains lime 9·6 and soda 9·4.

HUMBOLDTILITE, *Mellilite, Somervillite,* chiefly silicate of lime.

SARCOLITE.

LATROBITE, *Diplöite.*

RAPHILITE.

COUZERANITE.

Aluminous Hydrated Silicates with Alkaline and Lime bases, and their Isomorphs.

417. The group now to be considered includes a number of minerals greatly resembling each other; they are glassy, and frequently milk white, but admit of various tints of colour. They are neither very hard, nor very heavy. SG=1·95 to 2·7. They give off water before the blow-pipe, and are soluble in acids.

Many of the minerals of this group are called *Zeolites*, on account of their boiling and swelling when exposed to the heat of the blow-pipe flame. The following list contains the names of those determined by Dr. Thomson, and the more important of them will be found described in their places. Most of them, however, must be regarded as synonyms :—

Agalmatolite	Glottalite	Natrolite
Analcime	Gmelinite	Neurolite (?)
Antrimolite	Harmotome	Plinthite (?)
Apophyllite	Harringtonite	Pyrophyllite
Brewsterite	Heulandite	Rhodalite
Chabasite	Ittnerite	Scolezite
Chalilite (?)	Karpholite	Steatite
Chlorite	Laumontite	Stellite
Cluthalite	Lehuntite	Stilbite
Erinite	Levyne	Talc
Esmarkite	Mesotype	Zeuxite

418. MESOTYPE (Rhombohedral, H = 5 — 5·5, SG = 2·17 — 2·3). The following minerals are comprehended under this name, *Mesotype, Natrolite, Scolezite* and *Mesolite*. *Radiolite* or *Brevicite, Caporcianite, Lehuntite, Stellite, Harringtonite, Cluthalite, Poonahlite* and *Antrimolite* are varieties. They are all hydrous silicates of alumina and lime, or soda, and are chiefly volcanic, either recent or ancient.

419. STILBITE (Rhombohedral, H = 3·5—4, SG = 2·1 — 2·2). Occurs in amygdaloid ; is generally crystalline ; highly lamellar. White, red, grey, yellow and brown. It is a hydrous silicate of alumina and lime. *Spherostilbite* and *Hypostilbite* are closely allied.

420. HEULANDITE (Monoclinic, H=3·5—4, SG=2·1—2·2), including *Lincolnite* and *Aedelforsite*, is composed in nearly the same way that Stilbite is, but in somewhat different proportions. It is a volcanic mineral. *Epistilbite* is probably a variety.

421. The following are all hydrous silicates of alumina with lime, potash, soda, and other alkaline earths, and have little general interest. In some interesting species the per centage of alumina and other bases is given. It has not been thought necessary to mention the proportion of silica, nor must the quantities mentioned be regarded as invariable.

BREWSTERITE (contains strontia and baryta).

FAUJASITE contains about 17 per cent. alumina, with 10 per cent. lime and soda.

GISMONDINE, *Zeagonite*, *Abrazite*, contains about 26 per cent. alumina, with 14 per cent. lime and potash.

EDINGTONITE contains alumina 28, lime 13.

GLOTTALITE contains alumina 16, lime 24.

LAUMONTITE, *Leonhardite*, contains alumina 22, lime 12.

PREHNITE, *Koupholite*, in six-sided prisms or massive reniform and botryoidal, and of compact texture ; colour light green ; found in trap and other igneous rocks ; receives a handsome polish. (It contains alumina 23, lime 26.)

422. CHABASITE, with *Gmelinite* or *Hydrolite*, *Levyne*, *Lederolite*, *Phacolite*, *Acadiolite*, *Herschelite*, *Beaumontite*, *Haydenite* (Rhombohedral, H=4—4·5, SG=2—2·2). A group of minerals of rather doubtful identity, composed of nearly 50 per cent.

of silica with alumina, lime, soda, potash, and water. Form of crystals generally nearly cubical, but different in some varieties. (Alumina 20, lime 10, soda and potash 2.)

HARMOTOME, *Morvenite*, *Ercinite*, *Cross-stone*, a silicate of alumina and barytes. (Alumina 16, barytes 18.)

CHRISTIANITE, *Phillipsite* (Lime or Potash Harmotome). (Alumina 20, lime 6, potash 7.)

ANALCIME, *Cubicite*, *Sarcolite*. (Alumina 23, soda 14.)

ITTNERITE. (Alumina 28, lime 5, and soda 12.)

SCOULERITE, *Pipestone*. (Alumina 17, soda 12, with lime and magnesia.)

THOMPSONITE, *Comptonite*, *Chalilite*. (Alumina 31·6, lime and soda 17·2.)

KILLINITE.

AGALMATOLITE, *Onchosine*, *Figure stone*. (Alumina 33, potash 76.)

SAPONITE, *Piotine*, *Kerolite*, *Soapstone* (not *Steatite*).

RHODALITE, *Pagodite*.

VERMICULITE.

KARPHOLITE.

PYROSCLERITE, *Kammererite*.

KIRWANITE.

PYROPHYLLITE.

423. CHLORITE (Hexagonal, H=1–1·5, G=2·78–2·96). It is a silicate and aluminate of magnesia and iron. Under this species are included certain crystals formerly regarded as talc, which may be grouped under the names *Chlorite*, *Pennine* and *Ripidolite*. *Hexagonal chlorite* is generally greenish, massive, and granular, or in inelastic laminæ, and is very widely dispersed in rocks. *Pennine* is more crystalline, and *Ripidolite* of different crystalline form. Chlorite schist is a rock variety. All these minerals may be detected by the argillaceous odour given off on breathing upon them.

424. The following are all silicates in which alumina and iron play an important part.

LEPIDOMELANE, a black and micaceous mineral containing a large per centage of iron.

NACRITE, *Granular-talc*, contains potash.

WICHTINE, contains lime, magnesia, and soda.

SEYBERTITE, *Clintonite*, *Holmite*, *Holmesite*, *Xantophyllite*, Silicate and Aluminate of magnesia, calcium, and iron.

GEDRITE.

SISMONDITE.

BOMBITE.

Non-aluminous Silicates.

425. APOPHYLLITE (Square prismatic, H=4·5–5, SG=2·3–2·4). Occurs crystalline, and in lamellar masses; very nacreous; cleavage very perfect; colour, white and greyish. It is a hydrous silicate of lime and potassa, frequently with fluorine. *Tesselite* is another name for the mineral, and *Oxahverite* a variety. *Albin* is a white variety.

TABULAR-SPAR, *Wollastonite*, *Chelmsfordite*, Bisilicate of lime.

EDELFORSITE, Trisilicate of lime.

DYSCLASITE, *Okenite*, *Danburite*, Hydrous tetra-silicate of lime.

PECTOLITE, *Osmelite*, Silicate of lime and soda.

426. Talc, Silicate of magnesia (Rhombohedral and Monoclinic, H=1, SG = 2·68—2·9). A very soft mineral of eminently pearly lustre and unctuous feel. Colour, greenish white. Usually in foliated masses, but sometimes crystalline, stellate or divergent, easily separating into thin translucent plates, flexible, but not elastic. The purest variety is foliated, others are fibrous, and others take the place of mica in granite, producing the rock called *Protogine. Lapis ollaris* or *Potstone* is an impure variety, also called *Indurated talc* or *Talcose slate.*

427. Steatite. Another silicate of magnesia nearly resembling talc. It is presented in two states, both soft and soapy, but one more compact than the other. *French-chalk* and *Soapstone* are varieties of Steatite or synonyms. *Rensselaerite* is an American variety.

428. Serpentine, also called *Ophite,* includes several varieties; they are all hydrous silicates of magnesia with iron, manganese or chrome, and sometimes alumina. The following are varieties:—*Picrolite, Schiller asbestus* or *Baltimorite, Picrophyllite, Rhodochrome, Hydrophite* and *Chlorophyllite.* Precious serpentine is a beautiful and valuable marble, and when mixed with limestone constitutes *verd antique.*

Metaxite, Serpentine with asbestos.
Pyrallolite, an amorphous and impure silicate of magnesia.
Picrosmine, *Boltonite,* Hydrous silicate of magnesia.

429. Olivine, also called *Peridote* and *Chrysolite.* Silicate of magnesia and iron. (Prismatic, H=6·5—7, SG=3.34). The following are varieties:—*Limbilite, Chusite, Hyalosiderite, Goekumite, Batrachite, Tautolite* and *Knebelite.* An olive green mineral occurring usually in lava and basalt in embedded grains—translucent and glassy—cleaving readily. It is characteristic of some lavas, and is used occasionally as a gem.

Villarsite, Silicate of magnesia with iron and manganese.

430. Zircon, called also *Hyacinth, Jargon, Ceylanite. Malacon* is a variety. (Square prismatic, H=7·5, SG=4—4·7). This mineral occurs in crystals, and also granular. Colour, brownish red, and red of clear tints; also yellow and grey. Streak, uncoloured; lustre, adamantine; fracture, conchoidal and brilliant. It is a silicate of zirconium coloured generally with iron. Its hardness (near corundum) renders it valuable for jewelling watches. It is also sometimes set as a gem.

Aeschynite, Titanate of zirconia with several rare metallic bases.
Polymignite, another titanate of zirconia, &c.
Polycrase, Tantalate and titanate of zirconia with uranium, &c.
Wohlerite, Silicate and tantalate of zirconia, &c.
Oerstedite, Silicate and titanate of zirconia, &c.
Eudyalite, Silicate of zirconia, lime, soda, &c.

The next mineral is only interesting as giving an earthy element (*Thorium*) not met with elsewhere. It is

THORITE, Hydrous silicate of thorium.

We have next to consider a series of minerals of considerable importance in the composition of rocks, and having several bases. The first is the *Hornblende group*, including a considerable number of varieties. The name *Amphibole* is given by Dufrénoy to the principal species. The group of *Augites* will follow. Analyses of hornblendic minerals will be given in a future paragraph, and the minerals again referred to when rock masses are considered.

431. HORNBLENDE, or AMPHIBOLE (Monoclinic, H=5—6, SG=2·9—3·4). There are two principal sub-species, *Tremolite* or calcareous amphibole, and *Hornblende* or ferruginous amphibole, but they pass into each other.

Tremolite or *White Amphibole*, also called *Grammatite*, occurs generally fibrous, of greenish colour, and nearly transparent. *Actinolite* is a radiated variety, but is sometimes glassy. It occurs asbestiform or massive. *Compact Tremolite* is sometimes called *Jade*, and is used for various ornamental purposes.

Black Amphibole or true *Hornblende* is much more abundant than tremolite. It is generally in laminated masses, sometimes acicular as in *Strahlstein*, sometimes laminated, and sometimes granular as in *Pargasite;* or in globular masses, or compact as *Hornstone*. The colour is generally dark green, but not invariably. Hornblende is an essential ingredient of many rocks, such as syenite, trap, and hornblende-slate. *Arfvedsonite* is a variety containing 30 per cent. of oxide of iron. *Phyllite* is another ferruginous variety. *Polylite* has a smaller proportion of silica, but in other respects resembles hornblende; and *Diastatite* only presents some difference of crystalline form. Some varieties of *Asbestos* belong to Amphibole, but the whole group will be described under the species Pyroxene, to which it more properly belongs.

BABINGTONITE presents striking resemblances to Amphibole, and also to Tourmaline, but has been considered a distinct species.

432. PYROXENE, or AUGITE (Monoclinic, H=5—6, SG=3·2—3·5). This is the name given to a large group of minerals, presented under various external forms, and, like Amphibole and some others already described, offering very striking, though difficult cases, of isomorphism and dimorphism. Many divisions of the species have been suggested, but we retain that of Werner, advocated also by Dufrénoy, as best adapted for our purpose. According to this view, there are two principal groups, *Diopside* and *Augite*, the former chiefly occurring in igneous rocks, and the latter in modern volcanic districts. The Augites are all silicates of magnesia and lime, combined with one or more bases, of which protoxide of iron, and protoxide of manganese are most abundant. These bases all replace each other. This mineral occurs crystalline and massive, sometimes fibrous, sometimes granular, and sometimes compact. Lustre vitreous. Brittle.

433. DIOPSIDE or *White malacolite* is white or pale clear green, more or less transparent; *Sahlite* and *Baikalite* are darker green; *Mussite* occurs in long, flat, crystalline plates; *Coccolite* in grains, green or white; *Lherzolite* is compact; *Fassaite* and *Allalite* are names that have been given to other varieties; *Hedenbergite* and *Jeffersonite*

are ferruginous varieties. *Hypersthene* is a highly lamellar variety, also containing iron, but black, with metallic lustre; it has been called *Paulite.* Some manganese varieties will be described amongst the ores of manganese.

An important group of this sub-species is that which contains *Asbestos*, *Amianthus*, *Mountain-wood*, *Mountain-cork*, and *Mountain-leather*. These are some of them so fibrous that they admit of being woven into cloth, which from its incombustibility and the slowness with which heat passes through it is used as a defence in entering heated or burning places. Some kinds seem to be hydrous silicates of lime, magnesia, and iron, and might perhaps be regarded as a distinct species; others belong to the species Amphibole. *Zeuxite* is a distinct variety of diopside though resembling Amianthus.

Augite or *Black-pyroxene*, the form usually found amongst modern volcanic rocks, appears in black or greenish-coloured crystals, and contains a good deal of lime, as well as iron and magnesia. *Basalt* has been regarded as a massive form of this variety, and will be further described when treating of rocks.

A crystalline mineral has been described under the name of *Ouralite*, intermediate between amphibole and pyroxene.

434. Diallage (Monoclinic, H=4·5, SG=3·2—3·5). Silicate of lime and magnesia. This name has been applied to different minerals. It may be considered to include *Bronzite*, a mineral of greenish brown colour and metallic lustre, common in serpentine; and *Schiller-spar*, a dusky green mineral, brittle, and of metallic pearly lustre. The former abounds in magnesia, but contains very little lime. The latter is more calcareous. *Antigorite* is a variety of bronzite. *Smaragdite* is an emerald green mineral, also belonging to bronzite. *Göbhardite* is probably a variety of schiller-spar.

Retinalite; Hydrous silicate of magnesia and soda.

435. *Cronstedtite* or *Chloromelane*, of which *Sideroschisolite* is probably a variety, is a silicate of iron. *Hisingerite* or *Thraulite*, *Stilpnomelane*, *Chloropale*, *Herbeckite*, *Pinguite*, *Fettbol*, *Verona earth*, *Nontronite*, *Anthosiderite*, *Polyhydrite*, *Chamoisite* and *Xylite*, are also impure silicates of the same metal. Silicates of copper, zinc, and other metals are also known.

There are several other minerals consisting of hydrous silicates of iron and other bases, in which iron occupies so large a part that they will be more conveniently considered among the ores of that metal. As, however, they also belong to this place, it may be convenient to mention their names. They are *Jenite* (*Ilvaite*, *Lievrite*), *Wehrlite*, *Polyadelphite*, *Achmite*, *Crokidolite*, and *Commingtonite* (See § 460).

Silico-Fluates.

436. Topaz, Silico-fluate of alumina (Hexagonal, H=8, SG=3·5). Crystallizes in right rhombic prisms; cleavage perfect, parallel to the base. Colour wine-yellow, greenish, bluish, or reddish; streak white; lustre vitreous. Occurs generally in old porphyritic rocks in the Ural and Altai mountains, and also in Scotland. It is found in Brazil, frequently as a pebble. Employed in jewellery, the colour being altered by heat. Becomes electric by heat. Has two axes of double refraction. *Picnite* and *Pyrophysalite* are varieties; but the former is thought to differ in its crystalline system.

Chondrodite, *Brucite*, *Maclurite*, Silico-fluate of magnesia.

437. Mica, *Muscovy Glass.* A group of minerals having extremely perfect lamination and a marked semi-metallic lustre, more or less

pearly. They present several examples of isomorphism in the substitution of some of the alkaline earths for others, and an instance of dimorphism in the two varieties called *uni-axal* and *bi-axal* mica. Mica is important as forming one of the constituents of granite, and it is used in Siberia and elsewhere as glass, owing to its transparency, toughness, and perfect cleavage. According to Hauy, it may be divided into laminæ only $\frac{1}{250000}$th of an inch thick.

Potash mica or *Bi-axal mica* (Monoclinic, H=2—2·5, SG=2·65—3). Colour, shades of white, grey, green, brown, red, violet, and black; silver-white, greyish-green, and black, being the most usual. This is the common kind of mica, and generally occurs in thin foliated masses, plates, or scales, in granite and mica-schist. The usual composition is Silica, 46·3; alumina, 36·8; potash, 9·2; peroxide of iron, 4·5; fluoric acid, 0·7; water, 1·8.

Lithia-mica or *Lepidolite* occurs in crystals of purplish colour, and in masses of aggregated scales. Lithia here replaces a portion of the alumina to the extent of from 2 to 6 per cent, and the proportion of fluoric acid is much more considerable than in potash mica. It is monoclinic or perhaps triclinic.

Magnesia-mica or *Uni-axal mica* (Hexagonal, H=2·5—3, SG=2·85—2·9). In this mineral, a certain proportion of magnesia (10 to 26 per cent. of the whole mineral) replaces alumina, which is present only to the extent of about 15 per cent. The proportion of potash remains nearly the same for all varieties of mica, but is generally intermediate in this variety between the proportions met with in the two former. *Biotite* is another name for this mineral.

Fuchsite is a green mica containing chrome. *Plumose mica* is a variety in which the scales are arranged in a feathery form. The name *Rubellane* has been given to a red mica. *Margarodite* is a variety of common mica. *Hydrous-mica* contains 14 per cent. of water.

LEUCOPHANE contains 11½ per cent. of glucina.

Silico-borates.

DATHOLITE, *Esmarkite*, Hydrous boro-silicate of lime. (Monoclinic, H=5—5·5, SG=2·9—3.) Found crystalline and botryoidal, in the latter case called *Botryolite*. Colour, whitish; translucent. When abundant it is used in the manufacture of borax. *Haytorite*, and *Humboldtite* are varieties.

438. TOURMALINE (Rhombohedral, H=6·5–7·5, SG=3–3·3). Crystalline in prisms, also coarse columnar, and sometimes massive. Brittle. Lustre vitreous to resinous. Electrically polar when heated. Blue and green varieties exhibit dichroism. Black, or brown black is the more common colour, but red and yellow crystals occur. The composition of tourmalines is very varied and complicated; boracic acid, however, is an almost invariable ingredient, and there are three varieties, one containing a sensible proportion of lithia, another of soda, and a third of potash. Most specimens contain a proportion of iron or manganese oxides.

Rubellite is a red variety; *Indicolite*, an indigo blue; and *Brazil-emerald*, a green. Tourmaline was formerly called *Schorl*; but the latter name is now confined to a sub-species.

AXINITE, *Thumite*, *Yanolite*. In violet crystals, remarkable as one of the few representative forms of the unsymmetrical oblique prism.

Silico-Titanates.

439. SPHENE, *Titanite* (Monoclinic, H=5·—5·5, SG=3·4—3·6). A well-known mineral, coloured variously with greenish-grey, greyish, or reddish-green tints. It occurs in altered rocks, and consists of silico-titanate of lime. *Greenovite* is a rose-coloured sphene, containing manganese. *Menaccanite* is a dark variety. *Pictite* is dirty yellow. The name *Semeline* has been given to an orange-yellow variety.

MOSANDRITE contains also cerium and lanthanum.

Sulphur-silicates.

The minerals in this group contain sulphur. They are few in number, but one species has considerable interest.

440. LAPIS-LAZULI, *Lazulite*, *Ultra-marine* (Octahedral, H=5·5, SG=2·38—2·42). Generally massive; of a rich and brilliant azure blue colour, supposed to be due to the presence of sulphuret of sodium. Obtained from Persia, and near Lake Baikal in Siberia, in a vein with white calc-spar; also with iron pyrites. Crystallises rarely in dodecahedrons. It is used in mosaic-work and other costly inlaid furniture. When powdered it is manufactured into *ultra-marine*, but this has lately been made artificially. *Hauyne*, with a nearly allied mineral, *Spinellane*, also called *Nosean*, cannot with propriety be separated.

HELVINE is remarkable for containing sulphuret of manganese as one of the bases in the silicates of which it is composed. It is the only instance known in which a sulphuret acts in this way.

Aluminates.

441. SPINELLE, Aluminate of magnesia (Octahedral, H=8, SG=3·4—3·8). A common crystalline gem, resembling various precious stones, and deriving its ordinary names from those resemblances. The scarlet or bright red crystals are called *Spinelle-ruby*, the rose-red *Balas-ruby*, the orange-red *Rubicelle*, the violet *Almandine-ruby*, the green *Chloro-spinelle*, and the black *Pleonaste*. Opaque octahedral crystals are called *Ceylanite*. They are of the hardness of topaz. The colour is derived from oxides of iron, chrome, copper, or other metals. The mineral is found in igneous rocks, the black varieties in volcanic districts, and the lighter colours in granite and gneiss.

AUTOMOLITE, or *Gahnite*, resembles spinelle, but contains upwards of 30 per cent. of oxide of zinc.

DYSLUITE is a similar mineral with a large per centage of iron.

CHRYSOBERYL or *Cymophane*, Aluminate of glucina (Hexagonal, H=8·5, SG=3·69—3·78), is a beautiful and valuable gem, but rarely without flaws. Colour, bright green. H=8·5·, SG=3·69—3·78. Specimens from the Ural have been called *Alexandrite*.

TURNERITE; Aluminate of lime and magnesia.

CHAPTER X.

DESCRIPTION OF METALS AND METALLIFEROUS MINERALS OR ORES.

THE minerals that remain to be described are those to which the term *metallic* applies with more or less accuracy. They are collected together into one class, and include a variety of species of great interest and importance.

CLASS THE FIFTH.

METALS.

442. This class, as defined by Dufrénoy, includes two divisions, very easily distinguished by their aspect.

1. The native metals, and combinations of native metals with each other possessing a metallic lustre.

2. Combinations of metals with oxygen or with acids, not having generally a metallic lustre, and in this respect resembling the silicates in appearance. They have, however, a peculiar aspect, and a high specific gravity, and they almost always yield a regulus or metallic ash on trial with the blowpipe.

In the present chapter these various minerals will be grouped under the head of the metal most important in their composition, and, after a short notice of the metal itself, the chief ores, if any, will be alluded to, and the names only (with the composition) of the other minerals mentioned. All the metals will be found here, although some are also referred to in another chapter.

CERIUM.

443. This metal has no known use, and is only found in very small quantities, frequently with *Yttrium* and *Fluorine*. The chief minerals in which it occurs are from Sweden, and *Cerite* (a silicate) is the only one at all abundant or easily recognised. Cerium is named from its wax-like appearance (*Cēros* wax). (See *ante*, § 393.) The metal is said to be of whitish colour, brittle, infusible except before the oxy-hydrogen blow-pipe, and volatile when intensely heated. It conducts electricity badly.

CARBO-CERINE, *Parasite*, Carbonate of cerium.

CERIUM-OCHRE, Hydrous oxide of cerium.

CRYPTOLITE, Phosphate of cerium.

MONAZITE, *Edwardsite*, *Mengite*, *Eremite*, Phosphate of cerium, lanthanum, and thoria.

FLUO-CERINE, Fluoride of cerium.

BASI-CERINE, Hydro-fluoride of cerium.

ORTHITE, *Cerine*, *Allanite*, *Bodenite*, *Pyrorthite*. Silicates of the protoxides of

cerium, iron, and manganese, with alumina, yttria, and lime, water, and various impurities.

CERITE, Hydrous silicate of cerium.

TSCHEWKINITE, Silicate and titanate of cerium, lanthanum, and didymium, with oxide of iron.

MANGANESE.

444. The earthy oxides of this metal are very widely diffused over the earth, frequently in bands of small thickness between the oldest and secondary groups of rocks, but often in masses without any regularity, either parallel or transverse to the stratification. The sandstone called by foreign geologists *Arkose* is that in which these masses chiefly occur. The crystalline minerals of manganese are generally in thin veins. The metal when obtained resembles cast-iron, is moderately ductile, but breaks with a blow of the hammer; is fusible with great difficulty, rapidly tarnishes and falls to powder on exposure to damp air, decomposing water and giving off the odour of hydrogen when breathed on. ($SG=7{\cdot}86$.)

Manganese is not used in the arts in the metallic state, but its oxides are employed in bleaching to a very large extent, owing to the facility with which they part with their oxygen gas. Besides this use, the oxides are valuable in giving violet colours to glass, and removing brown and green tints from the same substance. The sulphate and chloride are used in calico-printing, and the sulphate gives a chocolate or bronze colour. *Wad*, one of the impure hydrous oxides, is used also as a coarse pigment, and in glazing pottery. The ores of manganese are generally associated with iron, often with barytes, and sometimes with cobalt.

MANGANESE-BLENDE, *Alabandine*; Sulphuret of manganese ($Mn\,S$).

ARSENICAL MANGANESE; Arseniuret of manganese ($Mn\,As$).

HAUSMANNITE; Sesqui-oxide of manganese.

BRAUNITE; Protoxide of manganese.

445. PYROLUSITE, Peroxide of Manganese (MnO_2, Hexagonal, $H=2-2{\cdot}5$, $SG=4{\cdot}7-5$). Colour blackish grey or black; generally massive, botryoidal, fibrous, earthy or compact, and often dendritic. This is the most common ore of manganese, and is much worked in various parts of Germany, in Thuringia, Westphalia, Moravia, Saxony, and Bohemia; in Hungary and France; in the United States; in Brazil; in England, in Cornwall, Devonshire, and Somersetshire; and in Scotland near Aberdeen. It contains very little water, and gives off 10 to 11 per cent. of oxygen at a red heat.

MANGANITE; Hydrous sesqui-oxide of manganese. This mineral is described by Beudant and referred to by Dufrénoy, as *Acerdese*. It is much harder than Pyrolusite ($H=3{\cdot}5$), containing oxygen in excess, and about 10 per cent. of water. The names *Newkirkite* and *Varvacite*, have been given to varieties. It has little value.

446. WAD, *Bog manganese*, also called *Earthy manganese*, a peroxide of manganese, with much water ($H=3$, $SG=2{\cdot}3-3{\cdot}7$). This ore is very impure, being mixed generally with oxides of iron,

cobalt, copper, and various other substances. It is used in bleaching, and in the manufacture of the pigment called *umber*, and when mixed with linseed-oil often takes fire spontaneously. It is found near Exeter, and in many places on the continent of Europe.

An aluminate of the peroxide of manganese occurs near Siegen on the Rhine, and appears to be a distinct mineral.

447. Psilomelane (H=5·—6·, SG=4·1—4·2), a doubtful mineral, probably a mixture of manganite of barytes or potash, with peroxide of manganese. It is an abundant ore, generally accompanying other ores of the same metal. It contains cobalt. *Heteroclin* and *Marceline* are similar ores, containing silica.

Diallogite, *Rhodocrolite*, Carbonate of manganese. (Hexagonal, H=3·5—4·5, SG=3·3—3·6.)

Hureaulite, Heterozite, and Triphylline, or *Triplite*, are phosphates of manganese and iron. Dufrénoy puts *Iron apatite* in the same list.

448. Bi-silicate of manganese, *Manganese-spar*, *Red-manganese*, *Horn-manganese*, *Hydropite*, *Rhodonite*, *Photozite* (Monoclinic, H=7, SG=3·54—3·68). A deep rose or flesh-coloured mineral, crystalline or granular, translucent at the edges, with irregular fracture. It is sufficiently common generally, though rare in England, and is found both in veins and beds. It is susceptible of a fine polish, and is used as an ornamental stone, and also in colouring glass and glazing pottery. *Troostite*, or *Troolite*, is a variety containing iron. *Bustamite*, *Opsimose*, and *Dyssnite*, are probably varieties obtained by partial decomposition.

Tri-silicate of manganese is a concretionary mineral, much lighter and less hard than the former, and very brittle. *Allagite* is a variety. All the silicates of manganese are doubtful, and contain many impurities and accidental substances.

IRON.

449. We have already mentioned iron as the most abundant and universal metal, and it is also the most useful. It is found in almost all minerals, combined with many metals directly, and with most indirectly, and with sulphur, silica, carbon, and other earths. The ores from which the metal is obtained are numerous, and for the most part easily recognised. They have a specific gravity below 8, and generally as low as 5 : their hardness is seldom more than 6·5. They belong to various systems of crystallization. Iron is also found native in masses, which seem in most cases to have passed through a portion or the whole of our atmosphere, but in this case there is always a certain proportion of nickel (from 1 to 25 per cent.), together with chrome, cobalt, and other metals, sulphur, magnesia, and often some portion of other alkaline earths. Stones of this kind are called *meteorites*, and they have been found in various parts of the world. They exhibit a hardness of about 4·5 and SG=7·3—7·8. They are magnetic, malleable, and do not rust so readily as iron

The largest known specimen is estimated to weigh 30,000 pounds. Other specimens of native iron are said to have been found, but are certainly extremely rare.

Pure metallic iron can only be obtained with great difficulty, and by chemical manipulation on a small scale. It is the most tenacious of all metals and highly ductile, but cannot be beaten into very thin leaves; a cylindrical wire, whose diameter is $\frac{1}{12}$th of an inch (2 millemetres), just breaking under a weight of 550 pounds (250 kilogrammes). It is most malleable at a temperature exceeding red heat. Cast iron fuses at 2786° Fahr., but malleable iron requires the highest heat of a smith's forge. Two pieces may be cemented together by hammering; this is called welding, and is usually aided by the mixture of a little sand, which forms a fusible silicate at the surface, and prevents oxidation. The iron obtained by the ordinary processes, and used in the arts generally, contains sulphur, phosphorus, carbon, and titanium. Its value differs according to the proportion in which some of these are present.

450. IRON PYRITES, *Marcasite, Martial pyrites, Mundic.* Bisulphuret of iron (Dimorphous, Octahedral and Hexagonal; $Fe\,S_2$; $H=6-6{\cdot}5$, $SG=4{\cdot}8-5{\cdot}1$). A well-known, very common mineral, of peculiar bronze-yellow colour, frequently found crystallized in cubes, and often radiated, or in masses of various forms. It occurs in rocks of all ages, and often contains a little gold. It is brittle, strikes fire with steel, and easily gives off a sulphurous odour when exposed to heat. It is of great use in the arts (though not as an ore of iron), since it affords a large part of the sulphate of iron and sulphuric acid of commerce, and much sulphur and alum. It is a mineral very much exposed to spontaneous decomposition. *White iron pyrites* is a second form of the mineral crystallizing in the hexagonal system; it is a little paler in colour than the other variety, and decomposes yet more readily. *Crucite* is a variety.

MAGNETIC PYRITES is a softer mineral, found chiefly in old rocks. It is of a reddish colour, and probably consists of $Fe\,S_2 + 6Fe\,S$.

451. ARSENICAL PYRITES, *Mispickel* ($Fe\,S_2 + Fe\,As$, Hexagonal, $H=5{\cdot}5-6$, $SG=6-6{\cdot}2$), is a silver white or almost steel grey mineral, generally crystalline, and occasionally used in the manufacture of arsenic, but of little value. One variety contains cobalt. An axotomous variety is considered by Dufrénoy a distinct species. LEUCOPYRITE is the name given to an arsenical iron with very little sulphur, and is called by Haidinger *Lölingite.* It appears to be an impure arseniuret.

452. MAGNETIC IRON ORE, *Octahedral iron ore, Oxidulated iron, Magnetite,* Peroxide and Protoxide of iron (Octahedral, $H=5{\cdot}5-6{\cdot}5$, $SG=4{\cdot}9-5{\cdot}2$). Colour iron black; streak black; brittle. A very generally diffused and important ore of iron, common in the

old rocks, and generally presenting, iron 71·785; oxygen 28·215; or peroxide of iron 69; protoxide of iron 31; and often 1 or 2 per cent. of silica, and some oxide of titanium. It is often magnetic, and always strongly attracted by the magnet. It is usually in octahedrons, but occurs also in sand, and sometimes fibrous or amorphous. Little of this ore is found in England, but in Norway, Sweden, and Russia nearly all the iron, for which those countries are celebrated, is made from it. It also forms the centre of a vast mass of iron ore in the isle of Elba, and is abundant in India, in North America, in Mexico, and in Brazil. Large amorphous specimens exhibiting polarity are called *lodestones* or *native magnets*. *Gillingite* is a variety.

FRANKLINITE is a peroxide of iron, probably combined with manganate of zinc. *Dysluite* and *Isophane* seem identical.

453. SPECULAR IRON ORE, *Red hæmatite, Micaceous iron, Oligist, Iron-glance.* Peroxide of iron (Hexagonal, H=5·5—6·5, SG=5·1—5·3). An ore of iron present in some of its varieties almost everywhere. Colour generally dark steel-grey, or iron-black, and when crystallised having splendent lustre. When pure the ore contains 69·34 iron, 30·66 oxygen, and is therefore a true peroxide, but it is generally mixed with impurities. The different varieties have been separated into two groups, including, 1st. the metalloid minerals; 2nd. the concretionary, generally known as *red hæmatite*, and the red earthy oxides.

The first group contains the *Specular iron*, very abundant at Elba, and in volcanic districts, and often presenting brilliant iridescence with perfect metallic lustre; the *Micaceous ore*, composed of flat spangles, which separate on touching, and soil the finger; and amorphous *Oligist*, called in Brazil *Itaberite* or *Martite*.

The second group includes all the red earthy oxides of iron, from the ochres to those having metallic lustre; all the red hæmatites, often brown, but forming a red powder, much used in burnishing, and also in mixing with poor iron ores in England; the compact red oxides; and the hydrous varieties found in grains. *Red chalk*, *Jaspery clay iron*, are varieties, and the clay ironstones, which supply the vast manufactures of iron in England and Scotland, are sometimes considered to be of this kind. They are, however, partly carbonates.

454. BROWN HÆMATITE. Under this name we include the numerous hydrous oxides of iron, to which the following names have been given: *Lepidokrokite*, *Limonite*, *Brown iron-stone*, *Gœthite*, *Oetite*, *Oolitic* and *Pisolitic iron ore*, *Turgite*, *Iron ochre*, and others. Its crystallization is unknown. H=5—5·5, SG=3·4—3·95. It is opaque; with a fine fibrous fracture; brown, yellowish-brown, yellow, brownish-yellow, or blackish-brown colour; and yellowish-brown

streak. It contains, when pure, rather more than 80 per cent. of the peroxide of iron, and from 12 to 18 per cent. of water. Under the names *Lepidokrokite*, *Gœthite*, and *Rubin-glimmer*, are included the crystalline varieties, while the various other minerals are amorphous or earthy. *Bog iron ore* is an impure variety, containing phosphorus (§ 459). *Gœthite* is considered to differ from the true Brown hæmatites by a different proportion of water. *Stilpnosiderite* seems also a variety. The Brown hæmatite is valuable in polishing. *Yellow ochre* is a common pigment. The mineral, if it occur in sufficient quantity, is valuable as an ore of iron.

455. SPATHIC IRON, *Sparry iron*, *Spathose iron*, *Brown-spar*, *Sphœrosiderite*, *Siderite*, *Clay iron stone*. Carbonate of iron. (Hexagonal, H=3·5—4·5, SG=3·7—3·9.) A very important ore of iron in various places, though not used much at present, so far as the purer and more crystalline forms are concerned. Analyses of various specimens show that protoxide of manganese is generally present with the iron, and magnesia is generally present with the lime, while the per centage of protoxide of iron varies from under 37 to nearly 64 per cent., with from 30 to 42 per cent. of carbonic acid. There is a strong tendency in these crystalline carbonates to assume a spherical form; and hence the name *Siderite* and *Sphœrosiderite*, from the starlike radiation that results.

Vast masses of the sparry carbonate occur in Styria and Carinthia, in the duchy of Nassau, in the Pyrenees, in Bohemia, and elsewhere. They are only partially worked.

Junkerite is a variety of this mineral. *Thomaite* is a carbonate of iron in rhombic prisms. *Mesitine spar*, a carbonate of iron and manganese, sometimes called *Rhomb spar*. *Oligon spar* is another variety.

456. The Clay iron stones of England, Wales, and Scotland, found and worked in association with the coal and limestone of the carboniferous period, contain from 50 to nearly 90 per cent. of carbonate of iron, mixed with much earthy and carbonaceous matter. They are of the first importance, owing chiefly to the almost indefinite quantity present, and the circumstances under which they occur. The total amount of iron made annually in the British islands is not much less than two millions of tons. Similar deposits occur in the coal formations of Belgium and Silesia.

The argillaceous or clay ironstone is of ash-grey colour, sometimes inclining to yellowish and bluish, also brown and reddish brown. The latter is usually the effect of exposure to weather or heat. It occurs in amorphous or flat tabular masses, also in globular and irregularly reniform masses; the latter are sometimes solid, sometimes hollow, or enclose the same substance in pulverulent state. In the latter case they are termed *ætites*. The fracture is even, earthy, sometimes flat conchoidal; occasionally the structure is slaty. It yields easily to the knife, and is meagre to the touch. SG=3·35. It blackens and becomes very magnetic before the blow-pipe. The following is the analysis of a specimen from Low Moor Iron-Works, near Bradford, Yorkshire, called *Black Iron-stone*, of the specific gravity of 3·035, by Mr. Richard

Phillips:—Protoxide of iron with a trace of oxide of manganese 43·26, carbonic acid 29·30, silex and alumina 20·78, carbonaceous matter 2·67, lime 1·89, moisture 1·00, loss 1·1.*

The following analyses of Clay ironstone nodules, chiefly from South Wales, performed at the Museum of Economic Geology, will be found useful.†

Name and locality of the bed.	Per centage of Metallic iron.	Carbonate of iron.	Carbonaceous matter.	Earthy matter.
Upper vein, Ystradgunlas	41·5	86·0	..	14·0
Maesteg Valley bed, No. 2	38·5	79·9	6·6	13·5
Black band, Beaufort Iron-Works, Pontypool	38·4	79·5	16·4	4·1
Maesteg Valley, No. 3, Lower black band	36·8	76·4	11·0	12·6
Pendaren red vein	36·4	75·4	..	24·6
A bed, Ystradgunlas	34·9	72·4	..	27·6
Black band, Lanarkshire	33·7	70·0	23·0	7·0
Maesteg Valley bed, No. 1	30·7	63·9	10·0	26·1
Nodules, Aberpergwm	29·4	60·9	..	39·1
Pendaren Jack vein	26·6	55·5	..	44·5
Cwm Avon bed	24·6	51·04	22·16	26·80

457. Chromic iron, *Chromite*, Chromate of iron and alumina (Octahedral, H=5·5, SG=4·4−4·5). This mineral consists of green oxide of chromium 60, protoxide of iron 20·1, alumina 11·8, magnesia 7·5. Occurs in octahedral crystals or massive, in small green fragments, attracted by the magnet. Colour iron-black and brownish-black. Found in serpentine and crystalline limestone, commonly in some of the Western islands of Scotland, either in veins, nests, or disseminated, but chiefly obtained from Sweden, the Ural, and the United States. It is much used in the preparation of pigments, and is an important and valuable ore.

458. The following minerals are of little practical importance. They are titanates and tantalates of iron and other bases, iron, however, being an important ingredient.

Ilmenite, *Crichtonite*, *Mohsite*, *Washingtonite*, *Mengite*, *Menachanite*. Titanitic iron contains from 8 to 53 per cent. of peroxide of titanium, and from 92 to 46 per cent. of peroxide of iron.

Iserine, *Gregorite*, *Gallizinite*, *Titaniferous sand*, *Nigrine*, another titanate of iron with manganese.

Tantalite, *Ferro-tantalite*, Tantalate of iron and manganese, with tin.

Columbite, *Baierine*, *Niobite*. Niobate and tantalate of iron and manganese with tin. Contains the new and rare metal Niobium.

Wolfram (H=5·−5·5, SG=7·1−7·5). Tungstate of iron and manganese, lime sometimes replacing part of the iron. This mineral, though of no value in itself, is not without interest in its association with the ores of tin, which it interferes with so much as sometimes to render the ore valueless. It is hard and of high specific gravity

* Phillips' "Mineralogy," 3rd edit. p. 237.

† "Memoirs of Geological Survey of Great Britain," vol. i. p. 186.

(H=5—5·5, SG=7·1—7·5); sometimes magnetic. Colour brownish-black, with a reddish brown streak. It fuses before the blow-pipe to a magnetic globule studded with crystalline points (See § 490).

459. The phosphates of iron are numerous, and possess some interest. The most common is that first named.

VIVIANITE, *Anglarite*, *Mullicite*. Blue phosphate of iron (Monoclinic, H=2, SG=2·66). There are two varieties of this mineral, one crystalline and the other earthy. The former contains Phosphoric acid 26·99, iron protoxide 42·10, water 28·50. The latter or earthy varieties contain more iron. Phosphate of iron is often found as an incrustation, and is sometimes used as a pigment. The earthy variety is called *Native Prussian Blue*. This mineral is found in many European countries and in various parts of America, often in an earthy friable state with what is called *Bog iron-ore*. The species thus named seems indeed to be an impure earthy phosphate combined with manganese and a large per-centage of water. It is earthy, friable, and amorphous; colour brown-yellow, blackish-brown, or grey; sometimes very abundant, and used in the manufacture of iron, though not well fitted for that purpose, owing to the presence of phosphorus. It is supposed to be derived from the decomposition of other rocks. It is found rather abundantly in Scotland and England, and contains about 66 per cent. oxide of iron.

DUFRÉNITE, Green phosphate of iron (Phosph. ac. 28·42; iron protoxide 57·60; water 12·15).

DELVAUXINE, Brown phospate of iron (Phosph. ac. 13·60; iron protox. 29; carb. lime 11; water 42·20).

KAKOXENE, Hydrous phosphate of iron and alumina.

460. The following are silicates of iron. Others have been already described (§ 424), and some, as *Green-earth*, or *Glauconite*, hardly admit of definite description. Some are used as ores.

YENITE, *Jenite*, *Liëvrite*, *Ilvaite*, is a silicate of iron and lime, containing upwards of 50 per cent. of oxide of iron. *Wehrlite* is a variety. POLYADELPHITE is another silicate of iron and lime, containing less iron (about 22 per cent.) and some magnesia and alumina. ACHMITE is a silicate of iron and soda, and KROKIDOLITE is a silicate of iron, magnesia, and soda. COMMINGTONITE is a silicate of iron, manganese, and soda.

BERTHIERITE, *Chamoisite;* a silicate and aluminate of iron. This mineral, containing 60 per cent. of protoxide of iron, is obtained in abundance from the green sand of Chamoisin, in the Valais, near St. Maurice, in Switzerland, where it is worked as an ore. It is attracted by the magnet; and there are several varieties furnishing three sorts of ore, the brown, blue, and grey, all oolitic and bedded.

CRONSTEDTITE. *Chloromelane*, is a silicate of iron, manganese, and magnesia. *Sideroschisolite* is very similar; but contains more iron.

HISINGERITE is another silicate of iron, and with it are associated the following minerals—*Stilpnomelane*, *Chloropale*, *Herbeckite*, *Fettbol*, *Verona earth*, *Nontronite*, *Anthosiderite*, *Xylite*.

PYROSMALITE is a silicate with 14 per cent. of muriate of iron.

461. The following are sulphates, arsenates, oxalates, and other salts of iron.

COPPERAS, *Misy*, Sulphate of protoxide of iron.

NEOPLASE, Red sulphate of iron. Sulphate of the protoxide and peroxide.

COQUIMBITE, Sulphate of the peroxide with water. This is white, and the so-called *Yellow sulphate* is another sulphate of the peroxide.

PHARMACOSIDERITE, *Beudantite*, *Cube ore*, Arsenate of iron.

SCORODITE, *Neoctese*, *Symplesite*. Another arsenate of iron.

ARSENIO-SIDERITE. Arsenate of iron and lime.

PITTIZITE, *Iron-sinter*, and *Fibro-ferrite*, are sulphates, phosphates, and arsenates of the peroxide of iron.

HUMBOLDTITE, or *Oxalite*, is an oxalate of iron.

CHROMIUM.

462. Chrome is a hard, brittle metal of greyish-white colour resembling iron, having a high metallic lustre, and exceedingly infusible. Its specific gravity is 6, but is rarely obtained in the metallic state and has never been used as a metal. It does not oxidise readily on exposure to the air, but combines readily with oxygen at a red heat. Combined with oxygen it appears as *oxide of chrome*, and with iron and lead it forms chromates of those metals (§ 457, 488). It occurs with iron in meteorites.

The ores of chrome are employed in the manufacture of chromate of potash, a yellow salt largely used by calico-printers. Mixed with a soluble salt of lead an artificial chromate of lead is produced of deep orange red or orange yellow colour, which forms an excellent pigment, used both in oil and water colours, in calico-printing and in dyeing. The oxide of chrome gives a green colour to glass and porcelain, and is the colouring matter of the emerald. Chromic acid enters into the composition of the spinelle ruby, and is employed in calico-printing from its power of discharging the vegetable and animal colouring matters.

CHROME OCHRE, Oxide of chrome. This mineral has been found in the Shetland Islands and in France in an earthy state—the proportion of oxide of chrome varying from 2½ to 25 per cent. *Wolchonskite* is a name given to a variety from Perm, in Russia. *Wiloschine* is another variety.

CHROMATE OF IRON has been already described (§ 457).

COBALT.

463. The metal Cobalt is of reddish steel-grey colour, brittle, rather soft, and capable of taking a high polish. SG=8·5. It alters less than iron on exposure and is rather less fusible. It has not been found native, and the metal is not employed in the arts, but its oxides are very valuable, being employed in the manufacture of a blue colour, much used under the names *smalt* and *zaffre* in the manufactures of porcelain and pottery. They are also used as pigments, "Cobalt blue" or "Thenard's blue" being prepared from the phosphate, and largely used by decorative painters and sometimes as a substitute for ultramarine. They are also employed in colouring glass and in painting on porcelain. The impure oxides employed in the arts are chiefly produced from the arsenical ores and the earthy oxide. About 650 tons weight of zaffre are annually obtained from various parts of Germany, and 200 tons of smalts from Norway. *Zaffre* is the impure oxide and of an intense blue colour. When melted with three parts

of sand and one of potash it forms a blue glass, and this pounded very small is called *smalts*. So intense is the blue afforded by zaffre that one grain will give a full blue to 240 grains of glass. Cobalt is generally found in nature combined with nickel and arsenic. The ores without metallic lustre have a reddish colour; those with metallic lustre are tin-white or pale steel-grey.

COBALT PYRITES, Sulphuret of cobalt.

464. SMALTINE, *Arsenical Cobalt, Tin-white Cobalt* ($Co\,As_2$, Octahedral, H=5·5, SG=6·4—7·3). A tin-white or steel-grey mineral, with dark grey or iridescent tarnish. Gives off garlic fumes when heated. The cobalt varies from 18 to 23·5 per cent., and the arsenic from 79 to 69 per cent. A variety with from 9 to 14 per cent. of cobalt is called *Radiated white cobalt*.

COBALTINE, *Grey cobalt*, another arsenical cobalt (Arsenio-sulphuret). *Danaite* is a variety. *Bismuth cobalt* is another variety.

465. EARTHY COBALT, Peroxide of cobalt (H=1—1·5, SG=2·2—2·6). Obtained with oxide of manganese. Colour black or blue-black. Very variable in the quantity of cobalt it yields, and at present little used. Found in Germany, the Ural, and England, and abundantly in Missouri and Carolina in the United States. *Horn cobalt* seems a variety.

466. COBALT BLOOM, *Erythrine, Peach-blossom ore, Red cobalt ochre.* Arsenate of cobalt (Monoclinic, H=2·5, SG=2·9—3). Found with other cobalt ores, and as an incrustation. It is valuable as an ore of cobalt. Colour peach and crimson red; transparent. Consists of oxide of cobalt 39·2, arsenic acid 37·9, water 22·9. *Roselite* and *Lavenduline* are probably identical. *Arsenite of cobalt* results from the decomposition of this and various arsenical ores.

COBALT VITRIOL, Sulphate of cobalt.

NICKEL.

467. Nickel is of brilliant white or greyish colour, ductile, more malleable than cobalt, and capable of being rolled and drawn into wire. SG=8·8. At low temperatures it is as magnetic as iron, but loses this property when heated. It is rather less fusible than iron. It is a useful and rather valuable metal, found native in meteoric iron, and associated with arsenic in various ores, none of them very abundant. It accompanies cobalt and silver, and sometimes copper. It does not oxidise on exposure at ordinary temperatures. An alloy of this metal with copper and zinc is much used as a substitute for plate in *German silver*, the usual proportions being, copper 100 parts, nickel 4, and zinc 6. The *White copper* of Germany is a similar alloy. The *Packfong* or *Tutenague* of the Chinese is also nickel with copper and zinc, but with the admixture of silver, cobalt, and iron. The ores of nickel have a metallic lustre and pale colour.

NICKEL PYRITES, *Capillary pyrites*, *Millerite*, Sulphuret of nickel.

BISMUTH NICKEL, Sulphuret of nickel and bismuth.

468. COPPER NICKEL, *Nickeline*, *Kupfer-nickel*, Arsenical nickel (Hexagonal, H=5·5, SG=7·3—7·7). Contains, Nickel 44, Arsenic 54; the arsenic sometimes replaced by antimony. Colour pale copper-red. Brittle. Metallic lustre. Found with cobalt and silver in veins, generally in old rocks in Saxony, Bohemia, and Styria, and rarely in Cornwall and Scotland. Used as an ore.

WHITE NICKEL, *Cloanthite*, another arsenical ore, much poorer in nickel, and not containing more than 20-28 per cent.

PLACODINE, a third ore also arsenical, with 57 per cent. nickel.

NICKEL GLANCE, a fourth, with 28—38 per cent. nickel and some sulphur.

AMOIBITE, a fifth, with 10 per cent. more nickel than the last, but 14 per cent. of sulphur.

ANTIMONIAL NICKEL, *Breithamptite*, contains Nickel, 29—33; antimony, 63—68, and is, therefore, represented by Ni Sb.

NICKEL STILBINE, *Allmanite*, an antimonial sulphuret of nickel.

NICKEL GREEN, *Tombazite*, Arsenate of nickel, with 36 per cent. of the oxide.

EARTHY OXIDE OF NICKEL.

GREEN HYDRATE OF NICKEL.

PIMELITE, a clay containing 15 per cent. of oxide of nickel.

ZINC.

469. Zinc is much used in the arts, generally in sheets. It melts at rather a low temperature (773° Fahr.), and boils at a white heat. It is so volatile as to be occasionally distilled. Its colour is bluish white, its fracture clean and laminated, and very brilliant. SG = 6·86—7·20, varying according to its condition, as cast or beaten. It is very easily oxidised, but the tarnish does not eat into the substance. It is not found native, but has long been used in the manufacture of certain metallic alloys, of which *Brass* is the best known. It is now, and has always been, obtained from the carbonate and silicate, which are very abundant in the lead districts of England (Derbyshire, Alston Moor, Mendip Hills, &c.), in Silesia, Poland, Carinthia, in Central and Eastern Asia, especially China, and in North America. It is malleable between 220° and 230° Fahr., and may then be hammered out, rolled into sheets, and drawn into wire. At higher temperatures, between 400° and 500° Fahr., it is so brittle that it may be pounded in a mortar. It is tough and intractable at common temperatures. Wire $\frac{1}{10}$th inch diameter sustains a weight of 26 pounds. In England the annual make is upwards of 1200 tons, and in Belgium and on the frontier of that country, 2600 tons. In Silesia, about 2500 tons are made every year.

Brass is made from copper and an ore of zinc (calamine). Zinc is much used now as a cheap substitute for lead in lining cisterns, covering roofs, forming water-spouts, and manufacturing many kitchen and dairy utensils. It is also engraved on (instead of stone) for

zincographic printing. The sulphate and oxide are employed in medicine. It is used by the Chinese as a coin.

470. BLENDE, *Black jack*, Sulphuret of zinc (Octahedral, ZnS, H=3·5, SG=4·16). Not much used as an ore, though very common. It is found abundantly with lead ores, and is sometimes accompanied by calamine. It is often phosphorescent by friction. *Marmatite* is a variety.

SELENIURET OF ZINC.

VOLZINE, Oxy-sulphuret of zinc.

471. CALAMINE, Carbonate of Zinc (Hexagonal, H=5, S.G.= 4·1—4·5). This is the usual ore of zinc, and the metal is obtained from it by distillation. It is crystalline, massive, or incrusting. Colour impure white, green, or brown. Subtransparent. Brittle. Effervesces in nitric acid. Contains about 65 per cent. of oxide of zinc (four-fifths of which is pure zinc), and about 35 per cent. of carbonic acid, but is often impure, containing iron, manganese, and cadmium. It occurs commonly with galena and blende in the Mendip Hills in Somersetshire, in Flintshire, Derbyshire, and elsewhere in England, in Belgium, near Aix-la-Chapelle on the Rhine, in Carinthia, Silesia, Hungary, Siberia, and in the United States. *Zinc Bloom* is an earthy carbonate, containing 15 per cent. of water. *Aurichalcite* is a variety, also containing water. The rare metal Cadmium is found with this ore. Pseudomorphous crystals are common, resembling Dog-tooth spar.

472. ELECTRIC CALAMINE was long confounded with calamine. It is, however, a true Silicate of zinc. ($2Zn\,S$ + Aq, Triclinic, H= 4·5—5, S.G.=3·35—3·45.) Colour whitish, bluish, greenish, or brownish. Transparent. Brittle. Strongly electric when gently heated, and some varieties become electric by friction. It occurs with calamine generally in the lead mines, and sometimes contains cadmium. It is valuable as an ore of zinc. *Mancinite* is also a silicate, and *Willemite* an anhydrous silicate.

HOPEITE, supposed to be a phosphate of zinc.

BRUCITE, Red oxide of zinc and manganese (Triclinic, H=4—4·5, SG=5·4—5·56). Colour deep or bright red; streak orange-yellow. A good ore when abundant, and one easily reduced, but it is nearly confined to North America. *Tephroite* is identical.

HYDRATE OF ZINC AND COPPER.

PYRRHITE, Oxide of zinc (?)

WHITE VITRIOL, Sulphate of zinc. It is supposed to arise from the decomposition of blende.

TELLURIUM.

473. Tellurium occurs native, and also in combination with gold, silver, iron, lead, and bismuth. Its colour is brilliant white, like that of tin; it is brittle, rather less fusible than lead, and combus-

tible. SG=6·115. It is extremely rare, and only found in the metallic state. It is of no use in the arts. The following are the most usual combinations :—

NATIVE TELLURIUM (Tellurium, iron, gold).
GRAPHIC TELLURIUM, *Graphic Gold*, *Aurotellurite* (Tellurium, gold, silver).
BLACK TELLURIUM (Tellurium, gold, lead, silver, sulphur).
FOLIATED TELLURIUM (Tellurium, lead, gold, copper, silver, sulphur).
BISMUTH TELLURIUM (Tellurium, bismuth, sulphur, selenium).
CARBONATE OF TELLURIUM, *Herrerite*, Carbonate of tellurium and nickel.

CADMIUM.

474. This metal occurs with ores of zinc chiefly in Silesia, in the proportion of from 2 to 11 per cent. It is also found in England in the form of sulphuret in the mineral called *Greenockite*. When reduced, the metal has the colour and lustre of tin, but with a shade of grey. It takes a high polish. It resembles tin not only in colour, but in softness, ductility, and in the peculiar creaking sound it emits when bent and heated. It is malleable, and fusible at 442° Fahr. SG=8·6. Its oxide and sulphuret produce fine brown and orange-yellow colours which may be used as pigments. The sulphate has been used in medicine. Some other uses have been suggested, of which the most important is coating iron tubes with a mixed deposit of copper and cadmium to supersede the so-called "galvanised iron," or iron dipped in melted zinc.

GREENOCKITE (Hexagonal, CdS, H=3—3·5, SG=4·8—4·9).

ANTIMONY.

475. Antimony is a silver-white metal, slightly blue, and with very brilliant lustre. Its hardness is about equal to that of gold. SG=6·7—6·8. Compact, and brittle. It does not oxidise on exposure at ordinary temperatures, but fuses a little below red heat and burns vividly. It is found native but not abundantly. It occurs generally with lead, silver, arsenic, &c., but the only important ore is the sulphuret. As a metal it is used in the manufacture of *type metal*, of which it forms from one fourth to a twelfth part, the rest being lead, with a little tin, bismuth, and copper. Mixed with lead alone it forms the rather brittle plates from which music is printed. *Hard pewter* is made of 12 parts tin and 1 antimony. *Britannia metal* of 100 parts tin, 8 antimony, 2 bismuth, and 2 copper. With iron it forms a hard whitish alloy. A very small quantity renders gold unmalleable. The sulphuret (crude antimony) has sometimes been used in the East to stain the hair of an intense black. The oxides are much used in medicine, and also in giving colour to factitious gems. Hungary alone supplies 600 tons annually, and large quantities are also obtained in England and France, and lately from Borneo.

NATIVE ANTIMONY, with a little silver.
STIBLITE, Antimonate of antimony.

ANTIMONATE OF LEAD (Ant. 31 per cent).

ARSENICAL ANTIMONY (Antimony 37 per cent., arsenic 62).

476. GREY ANTIMONY ($Sb. S_3$, Rhombic H=2, SG=4·6–4·7). An important mineral, containing, ant. 73, sulph. 27. Colour lead-grey. Sectile, cleaving readily. Often in long prismatic or acicular crystals, with strong vertical striæ. Occurs in masses or veins in the metamorphic and igneous rocks. Often compact and sometimes capillary. It fuses rapidly in the flame of a candle. It resembles the oxides of manganese, but is easily distinguished by its cleavage.

ZINKENITE, Sulphuret of antimony and lead (proportion of antimony 45 per cent.).

PLAGIONITE do. (Ant. 38 per cent.).

FEATHER ORE, Sulph. of ant. and lead (Ant. 31 per cent.).

BOULANGERITE, Sulphuret of ant. and lead (Ant. 25½ per cent.).

JAMESONITE, do. with iron and bismuth (Ant. 35 per cent.).

RED ANTIMONY, *Kermes mineral*, *Antimony blende*, Sulphuret and oxide of antimony (Ant. 75 per cent.).

WHITE ANTIMONY, Oxide of antimony ($Sb_2 O_3$).

ANTIMONO-PHYLLITE, an impure oxide of antimony.

ANTIMONIC ACID.

ANTIMONIOUS ACID.

In addition to these are several other sulphurets of antimony and lead, which must be regarded as ores of lead. These are *Steinmannite*, *Killbrickenite*, *Kobellite*, *White silver*. *Geokronite* and *Boulangerite* are sometimes regarded as belonging to this group.

BERTHIERITE, *Haidingerite*, Sulphuret of antimony and iron. (Ant. 52 per cent.)

ARSENIC.

477. Arsenic occurs in a native state, nearly pure, and also with many other metals, especially iron, cobalt, nickel, silver, copper, antimony, and manganese. It is a bluish-white or steel-grey metal with brilliant lustre. It is very soft (H=3·5) but brittle, and has a granular fracture and granular or lamellar texture. Its specific gravity is 5·7–6. At a high temperature (365°) it volatilizes and is readily inflammable, giving off a strong odour of garlic. It readily tarnishes, becoming almost black by exposure to the air.

Arsenic combines with oxygen in *White arsenic* (arsenious acid) and with sulphur in two forms, both common and valuable minerals. It also forms *arseniurets* with various metals, many of which have been described. It is used in the arts as a metal, in mixture with lead, to manufacture shot, its effect being to make the lead break readily in drops. It is also an ingredient in several alloys of lead, antimony, bismuth, &c. White arsenic is used in medicine, and in the manufacture of glass, and by candle-makers, and the sulphurets (*realgar* and *orpiment*) are valuable pigments, used both in dyeing and in the fine arts. Arsenic acid forms many metallic and other salts, called *Arsenates*.

WHITE ARSENIC ($As_2 O_3$).

PHARMACOLITE, Arsenate of lime.

478. Realgar, Red sulphuret of arsenic. (AsS.) Found in oblique prisms or massive; of a beautiful clear cochineal or orange-red colour. Transparent. $H = 1{\cdot}5 - 2$, $SG = 3{\cdot}35 - 3{\cdot}65$. Found chiefly in Transylvania and Hungary, with tellurium and gold; also from China. Used in fireworks. Contains 70 per cent. arsenic.

479. Orpiment, Yellow sulphuret of arsenic (As_2S_3, $H=1{\cdot}5$, $SG=3{\cdot}48$). Rarely crystalline. Contains 61 per cent. of arsenic. Subtransparent. Sectile. Obtained from Hungary, Turkey, China, South and North America. Made use of as the basis of the pigment called *King's yellow.*

MERCURY.

480. Mercury is found native in association with the sulphuret or chloride, the only ores. It is fluid at ordinary temperatures, has a silver-white colour and brilliant lustre. $SG = 13{\cdot}596$. It solidifies at $-39°$ Fahr. and volatilises very easily. Its principal use is in the preparation of silver and gold. The annual supply from all sources is about 1600 tons. When solid, mercury is malleable. In its ordinary state it combines very readily with some metals, as gold, silver, and tin. It tarnishes readily on exposure.

In addition to the use of mercury in the amalgamation of the ores of the precious metals, it is employed in gilding, in silvering mirrors, in filling thermometer and barometer tubes, and in various philosophical instruments. The salts of mercury are used in medicine.

Native amalgam (Mercury and silver, with 64—72 per cent. of mercury).

481. Cinnabar, Sulphuret of mercury (HgS, $H=2{\cdot}5$, $SG=8{\cdot}098$); contains 86·29 per cent. of mercury. The principal ore of mercury. Colour bright red to brownish red; streak red. Found crystalline in tabular or six-sided prisms, and massive. Sectile; nearly opaque. It occurs with talcose and argillaceous slate, or with porphyries, in rocks of various ages, and is volatile, and easily reduced. The principal mines in Europe are in Idria, Almaden, and the Palatinate (on the Rhine near Bingen); it is found in Peru, Chili, and Mexico; and lately very abundantly in California. It is used as a pigment, under the name *vermilion*, but chiefly in the preparation of the metal by distillation.

Horn quicksilver (Chloride of mercury), is a tough sectile ore found in the Almaden and Ober Moschel (Rhine) mines.

Selenide of Mercury.

Iodic mercury.

TITANIUM.

482. Titanium, although a metal, and occurring sometimes native, has more analogies with silica than with the metallic minerals generally. It occurs chiefly in nature in combination with oxygen, forming *titanates* of various earths and metals, and is very universally diffused with quartz and iron.

When obtained artificially as a metal or in the slags of iron-works, (where it is found not unfrequently in the form of brilliant cubic crystals*), titanium is found to be of copper-red colour, very brittle, hard enough to scratch quartz and steel, very light (SG=5·3), and infusible at all ordinary temperatures, not being affected by the highest heat of the blast furnace. In a crystallised state it is not acted on by acids, but when powdered is less refractory. Titanium is at present little used for any practical purpose, but an attempt was once made to employ it as a pigment.

RUTILE, *Nigrine*, Titanic acid, a reddish-brown mineral, found in altered rocks, and used to a small extent in painting on porcelain, and in enamelling artificial teeth.

ANATASE, another variety of Titanic acid.

BROOKITE, a third variety.

WARWICKITE, Fluoride of titanium and iron.

SPHENE is a silico-titanate, and is mentioned with some other salts of this metal in a former paragraph (§ 439).

MENACCANITE, Titaniferous iron.

483. TANTALUM or COLUMBIUM, NIOBIUM, PELOPIUM, and ILMENIUM, are other metals which may be mentioned here, but of which too little is known to admit of further reference. They are none of them at all employed in the arts.

TANTALUM or COLUMBIUM combines with oxygen, forming an acid whence are produced several compounds called *tantalates*. (SG=6.) It appears hard, and is infusible before the smith's forge, though fusible by the aid of the oxy-hydrogen blow-pipe.

LEAD.

484. Lead is a metal of great importance in the arts. It is found native, but only very rarely, being usually in combination with silver, antimony, arsenic, selenium, sulphur, molybdenum, chrome, and various acids. The only important ore is the sulphuret. Lead when pure is of bluish grey colour, tarnishing black. H=1·5, SG=11·3 – 11·4. It is ductile and malleable, but the least tenacious of all metals. Its texture is close like that of gold or silver. It is inelastic and one of the least sonorous of the metals. It melts at 612° Fahr., soils the fingers when rubbed, and marks paper. It emits a peculiar odour when rubbed in the hand. It is apparently soluble to some extent in perfectly pure water, and as the solution is poisonous cannot safely be used for culinary purposes. Lead oxidises readily on exposure, but not deeply, assuming a dull earthy aspect. It may be considered as the most abundant and most widely diffused metal after iron; about 55,000 tons are annually produced from the British mines only.

Metallic lead is much used in the arts in various ways: in thick sheets for roofing, lining cisterns, &c., and also in much thinner sheets for smaller works; it is cast into pipes for conducting water,

* These crystals are now regarded as cyanide and nitruret of titanium.

gas, &c.; alloyed with tin to make *solder*, and in the manufacture of *pewter;* and with antimony and tin in type metal; alloyed with arsenic it forms shot; combined with oxygen it forms *massicot* and *litharge*, both protoxides, and the latter of them used in the manufacture of flint glass and in separating silver from lead ores; it forms also *red lead*, a deutoxide used in the manufacture of flint glass and as a pigment; the carbonate or *white lead* is a well-known paint, and the chromate a yellow pigment; the acetate, *sugar of lead*, is used in various ways in medicine and the arts.

485. GALENA, *Lead glance*, Sulphuret of lead, almost always containing silver. (PbS, H=2·6, SG=7·57.) This very important mineral occurs in cubical crystals, in coarse or fine granular masses, or fibrous. When pure the proportion of lead is 86½ per cent., and there is generally some silver, varying indefinitely in amount, but, if present in no larger a proportion than 1 part to 10,000 (3 ounces to the ton), the silver can be separated with advantage in reducing the ore. Galena has a brilliant metallic lustre and lead-grey colour, and is brittle. The principal localities for this mineral in England are Durham and Northumberland, Cumberland, Yorkshire, Shropshire, and Cornwall; Cardiganshire and Flintshire, in Wales, Ireland, Scotland, and the Isle of Man also yield a considerable quantity. It occurs in Saxony, the Hartz, Spain, and France, in various places; in Belgium, near Namur; in Bohemia; in Siberia and in many places in Asia; and in North America in the Missouri district, in vast abundance. It is usually in veins. *Cuproplumbite* is a galena with 24½ per cent. of sulphuret of copper.

The following names have been given to minerals in which sulphuret of lead is the principal ingredient, but in which antimony, bismuth, iron, copper, or other substances, replace a portion of the lead. In the opinion of M. Dufrénoy, these are not sufficiently definite to be regarded as species.

Steinmannite, Sulphuret of lead and antimony, proportions unknown.

Kilbrickenite, Sulphuret of lead and antimony, with arsenic, and iron, or copper (lead 68·87, iron 0·38, antimony 14·39).

Kobellite (Antimony 9·24, lead 40·12, bismuth 33·3, iron 2·96, copper 0·80).

Weissgültigerz (rather an ore of silver than lead, containing in one specimen 20 per cent. of silver, and 48 of lead).

GEOKRONITE, Antimono-arseniuret of lead, Pb_5 (Sb As_3).

COBALTIC LEAD ORE, Arseniuret of lead containing cobalt.

BOULANGERITE, *Plumbostib.* Antimono-sulphuret of lead.

DUFRENOYSITE, Arseno-sulphuret of lead.

CLAUSTHALITE, Selenid of lead.

TELLURID OF LEAD.

BOURNONITE, Antimono-sulphuret of lead.

486. The following are oxides and sulphates of lead.

MASSICOT, Yellow oxide of lead.

NATIVE MINIUM, Red oxide of lead. The red lead of commerce is an artificial product. *Plumbic ochre* is a similar ore of yellow colour.

SULPHATE of LEAD, *Anglesite*, a mineral sparingly distributed, but found occasionally with galena. *Cupreous anglesite* is a hydrous azure-blue sulphate of lead and copper, found chiefly at Lead-hills, and a *Cupriferous sulphate of lead* also exists.

487. WHITE LEAD ORE; Carbonate of lead (H=3–3·5, SG=6·47). A white or greyish mineral, worked for lead when abundant, and affording, when pure, 75 per cent. of the metal. With sulphate of barytes it forms the pigment called *Venice white*.

DIOXYLITE, Sulphato-carbonate of lead.

LEADHILLITE, Sulphato-tricarbonate of lead.

CALEDONITE, Cupreous sulphato-carbonate of lead.

488. PYROMORPHITE; Phosphate of lead (H=3·5–4, S G.=6·5–7). A bright green or brown mineral, sometimes orange-yellow, owing to the admixture of chromate. Streak nearly white; lustre resinous. *Polysphœride* and *Muscoide* are varieties.

MIMETINE, Phosphato-arsenate of lead. *Hediphane* is a variety. *Nussierite* is another mineral referable to the same species.

HYDROUS ARSENATE OF LEAD.

CORNEOUS LEAD, Chloro-carbonate of lead.

CERASITE, *Cotunnite*, Chloride of lead.

VANADINITE, Vanadate of lead.

CROCOISITE, Chromate of lead. The pigment called *chrome yellow* is obtained from this mineral. It contains chromic acid 31·85, protoxide lead 68·15.

MELANOCHROITE, Subsesqui-chromate of lead (23·64 per cent. chromic acid).

VAUQUELINITE, Chromate of lead and copper.

MOLYBDATE OF LEAD.

TUNGSTATE of LEAD.

PLUMBO-RESINITE, a doubtful mineral containing oxide and phosphate of lead, alumina, and water.

ANTIMONATE OF LEAD.

TIN.

489. A useful metal, of silver-white colour, having a peculiar taste, and an odour recognized when the metal has been long held in the hands. Tin is very malleable, and may be beaten into very thin plates, especially at a temperature about that of boiling water. It has, however, little tenacity, a wire of $\frac{1}{12}$th of an inch breaking with a weight of about 50 pounds, and it is not very ductile though more so than lead. It may be beaten into leaves $\frac{1}{1000}$th of an inch thick. It is very fusible, melting at 442° Fahr. (a temperature 170° below the melting point of lead), and burning with a bright flame. It gives out a peculiar cracking noise when bent, but is scarcely if at all elastic. Its specific gravity is 7·28, but may be a little increased by hammering.

Tin oxidises slowly on exposure, whence its value in coating iron and copper. It alloys freely with quicksilver, bismuth, lead, and other metals.

The principal ore of tin is the oxide, and it is obtained chiefly from the south-west of England, Saxony, Bohemia, and Hungary in Europe, and from Malacca and Banca in the East Indies. It is also

found in Chili and Mexico, and occurs in many other mineral districts, but in very small quantities. About 5000 tons are produced annually in England, and not more than that quantity from all other known localities. Tin is much used in the manufacture of tin-plate (iron coated with tin) and for tinning copper, and also as tin-foil, which, alloyed with quicksilver, forms the reflecting surface in glass mirrors. The salts, dissolved in muriatic acid, are used in dyeing and calico-printing, and the metal is alloyed with copper in various proportions, to form bronze, bell-metal, speculum metal, &c.

NATIVE TIN.

TIN PYRITES, *Bell metal ore*, Sulphuret of tin.

490. TIN ORE; Oxide of tin (StO_2 H=6·5, SG=6·9). The only important ore of tin. Occurs crystallised, massive, or in grains; frequently as gravel. Colour brown or black; in veins in crystalline rocks, often with wolfram, copper, and iron pyrites, and other minerals. *Wood tin* is the name given to botryoidal and reniform shapes, with concentric and radiated structure. *Toad's eye tin* is the same variety on a small scale. *Stream tin* is the gravel-like ore found with detritus.

Tin ore resembles in colour and form, several minerals, from which it is often desirable to distinguish it. The principal of these are *Brown idocrase*, *Zircon*, *Zinc blende*, some *tantalates*, and *Wolfram* (tungstate of iron). Its high specific gravity is a sufficient characteristic with respect to the three minerals first named, of which the specific gravities are 3·3, 4·4, and 4·1, respectively, instead of 6·9. The tantalates are not so hard, barely scratching glass and being readily scratched by steel. Before the blow-pipe, the oxide of tin gives metallic tin with soda, and an opal white enamel with borax. The tantalates colour borax yellowish-green, like oxide of iron, and wolfram is lamellar and readily fusible.

BISMUTH.

491. A metal of considerable interest and some value, employed in the arts in a variety of ways. It is chiefly found native, and the whole supply at present comes from Saxony. It has a greyish or reddish-white colour, with a distinct reddish shade. SG=9·9. The metal crystallises readily in cubes. Its texture is generally crystalline. It is brittle—of hardness between copper and lead, breaks under the hammer, and cannot be drawn into wire. It fuses at 497° Fahr. It is not a common metal, and is usually associated with iron, arsenic, and other metals, or with sulphur and oxygen. Native bismuth is occasionally found.

When mixed with other metals, bismuth generally renders them more fusible, but this is not the case when only present in small quantity. The uses of bismuth are in the manufacture of type-metal, and of some kinds of solder; it is also used in the form of nitrate as a cosmetic (*Pearl powder*). *Plumber's solder* consists of 1 bismuth, 5 lead, and 3 tin. A mixture of 8 bismuth, 5 lead, and 3 tin constitutes a fusible metal which melts at a heat a little below that of

boiling water (200° Fahr). A small addition of mercury adds to the fusibility. The nitrate of bismuth is employed as a mordant for lilac and violet dyes in calico printing.

SULPHURET OF BISMUTH contains 81 per cent. bismuth, and fuses in the flame of a candle.

ACICULAR BISMUTH, Sulphuret of bismuth, lead and copper, with gold.

TETRADYMITE, Tellurium and bismuth.

BISMUTH OCHRE, Oxide of bismuth with carbonate of iron.

BISMUTITE, Carbonate of bismuth.

BISMUTH BLENDE, Silicate of bismuth.

URANIUM.

492. A very combustible metal, burning in the air at a temperature of 400° Fahr., but unaltered by exposure at ordinary temperatures. It more resembles the metallic bases of the alkaline earths, and especially magnesium, than the true metals; it has, however, a metallic lustre equal to that of silver, and it is malleable to a certain extent. Its colour is greyish or reddish-brown. SG=9. It is almost infusible. The oxides of Uranium are used in the porcelain manufacture as a pigment, yielding a fine orange tint in the enamelling fire, and a black colour in that in which the porcelain is baked.

PITCHBLENDE, Oxide of Uranium (UO. H=5·5, SG=6·35—6·48). A greyish, brownish, or velvet black mineral, often massive; opaque; dull; containing 79 to 87 per cent. of protoxide of uranium with silica, lead, iron, and some impurities. It occurs in veins with ores of lead and silver in Saxony, and with tin in Cornwall. *Uranic ochre* is a hydrous peroxide found with pitchblende. It is a yellow pulverulent mineral. *Coracite* resembles pitchblende, but contains alumina. *Gummi-erz*, or hyacinth-red pitchblende, is a variety with Vanadium. *Pittin-erz* is another variety.

URANITE, Phosphate of Uranium. This includes two minerals, *Uranite* and *Chalkolite*, the one containing phosphate of lime, and the other phosphate of copper, combined with the phosphate of uranium. They are very brittle, the former is of bright clear yellow, and the latter of green colour. H=2, SG=3·12 or 3·33.

SAMARSKITE, *Urano-tantalate*, Oxide of uranium with niobic and tungstic acids.

JOHANNITE, *Uran vitriol*, sulphate of uranium.

TUNGSTEN.

493. Tungsten is a hard brittle metal of light steel-grey colour and brilliant metallic lustre. SG=17·5. Barely fusible at the greatest heat of the smith's forge, but when heated to redness in the open air it burns into the peroxide (tungstic acid). Its ores, tungstates of lime, iron, and manganese, are very frequently associated with those of tin, and injure the latter greatly. *Tungstic acid* has been found native. No use has been made of it in the arts, nor have any of its compounds been found valuable.

WOLFRAM, Tungstate of iron and manganese (see §§ 458, 490).

TUNGSTATE OF LEAD.

TUNGSTATE OF LIME.

TUNGSTIC OCHRE.

MOLYBDENUM.

494. Molybdenum is a silver-white, brittle, very infusible metal; not to be procured in buttons by the heat of the smith's forge, and having a specific gravity of 8·64. It oxidises readily. It occurs in nature with sulphur and oxygen, and also with lead as *Molybdate of lead.* The sulphuret resembles lead and is remarkably unctuous to the touch, by which it may be readily distinguished. This metal has been little used in the arts.

MOLYBDENITE, Sulphuret of molybdenum ($Mb\ S_2$). Used sometimes in colouring porcelain.

MOLYBDIC OCHRE, Molybdic acid, or oxide of molybdenum.

VANADIUM.

495. A silver-white metal, obtained from some Swedish ores of iron, and from *Vanadinite* (a vanadate of lead), and vanadates of copper, or combined with lime. It has no value in the arts, unless a suggestion to employ vanadate of ammonia as a writing fluid should be found of importance.

COPPER.

496. This very important metal has been known from the earliest times, and is used in a vast variety of operations in the arts. It is, when pure, of a peculiar and characteristic red colour, and transmits a beautiful green-coloured light when in extremely thin pellicles, obtained by a chemical process. Its density varies. SG=8·78—8·96. It acquires a disagreeable odour by rubbing, and has a distinct taste. It melts at the temperature of 1996° Fahr., and at a white heat burns with a green flame. It is very malleable, being reduced by hammering into thin leaf, and it is also capable of being drawn into very fine and strong wire. A thread whose diameter is $\frac{1}{10}$th of an inch supports a weight of 300 pounds. Copper is the most sonorous of all metals; it is harder and more elastic than silver. It bears exposure to dry air perfectly unaltered, but damp air and acid vapours convert it into a green substance, called *verdigrease.*

Copper is found native in Cornwall, in the Ural mountains, in China, and in Brazil, either in octahedral crystals (H=2·5—3, SG =8·58) or in threadlike, mosslike, or arborescent shapes, generally in granite or metamorphic rocks, and especially at their junction. It generally contains silver. It is also found native in very large masses in volcanic rocks on the shore of Lake Superior, where one lump has been quarried whose weight was estimated at 80 tons; it measured 50 feet in length, 6 feet deep, and averaged 6 inches in thickness. Silver is not associated with these masses in the shape of alloy, but intimately mixed in grains and strings.

The chief ores of copper from which the metal is obtained for the market are the yellow and grey sulphurets, the oxide, and the carbonate. The solutions of the sulphate also yield some portion. The

quantity of metal obtained from Europe is about 26,000 tons annually; in addition to which a large quantity is brought from Chili, from South Australia, and lately from North America. The ores from Cornwall and Devon yield about 12,000 tons annually.

Copper is used by itself as a metal very extensively in the manufacture of machinery of various kinds and in sheathing ship's bottoms. It is also alloyed with tin in *bronze, speculum metal,* and *bell-metal;* with zinc in *brass, pinchbeck, tombac,* and *Dutch gold,* and with nickel in *German silver;* it is worked for ornamental purposes in the form of *Malachite* (green carbonate); *Azurite* (the blue carbonate) is used occasionally as a gem; and the sulphates are valuable in dyeing. Other salts are employed in the manufacture of blue and green colours and in medicine.

497. VITREOUS COPPER ORE; Bi-sulphuret of copper (Cu_2S, containing sulphur 20·6, copper 77, iron 1·5; Rhombic; H=2·5, SG=5·5—5·8). Colour blackish lead-grey, tarnishing blue or green; lustre dull. Fusible in the flame of a candle; soluble in nitric acid. Resembles sulphuret of silver, but is easily distinguishable by the blow-pipe button or by the colour of the solution in nitric acid, which is, in this mineral, green. This is one of the most important of the ores of copper, and is found with other ores in Cornwall, Scotland, Saxony, Silesia, Norway, Siberia, and the United States. It passes into *Black copper ore,* and is accompanied by *Variegated vitreous copper.*

STOMEYRINE, Sulphuret of silver and copper (H=2·5—3, SG=6·2—6·3), found massive or crystalline. Contains silver 52·9, copper 31·4, and sulphur 15·7. Colour like the former, but with brighter lustre.

BLUE COPPER, *Covelline, Indigo copper.* Sulphuret of copper (Cu S, sulphur 32·, copper 66·, H=2 SG=3·8).

SELENID OF COPPER.

EUKAIRITE, Selenid of silver and copper.

PHILLIPSITE, Sulphuret of copper and iron ($FS+2Cu_2S$, H=3, SG=5), containing copper 61, iron 14, sulphur 27·75. It is an ore found in Tuscany, and worked there. Colour reddish-brown, fracture reddish, conchoidal and unequal.

498. COPPER PYRITES; Sulphuret of copper and iron (Sulphur 36·2, copper 33·8, iron 30·; Square Prismatic, H=3·05, SG=4·17). This is the most important and most abundant ore of copper in England, Sweden, and various other places. It occurs in tetrahedral or octahedral crystals, and in dendritic forms, but most frequently massive. It is of brass-yellow colour, high metallic lustre, and frequently iridescent. (*Peacock ore.*) It is often much mixed with iron pyrites. It resembles native gold and iron pyrites, and sometimes tin pyrites, but is easily distinguished by its greater hardness and shade of colour from the first-named mineral, by its less considerable hardness from the next, and by its behaviour under the blow-pipe from the latter. It resembles also Phillipsite, from

which it may be distinguished by its lower specific gravity, and the colour, when newly fractured. The average quantity of metallic copper yielded by the ore is often only about 8 or 9 per cent.

499. GREY COPPER ORE; *Fahlerz.* A mixed sulphuret, containing, sulphur 26, antimony 24, copper 35, with variable proportions of arsenic, zinc, and silver. It corresponds with another ore, called *Silver Fahlerz,* in which silver replaces the copper. H=3·5, SG=4·6 – 5. Brittle. Colour steel-grey; bright metallic lustre.

TENNANTITE, Arseniferous grey copper.
ARSENICAL COPPER (Cu_3 As).

500. RED COPPER ORE (Cu_2O) contains copper 88·78, oxygen 11·50. (H=3·5 – 4, SG=6.) It has a deep red colour of various shades, and is found crystalline, massive, and earthy, but is not present in sufficient abundance to be used as an ore. A variety, of brick-red colour, occurs in Siberia, and is called by the German mineralogists *Ziegel-erz,* or tile-ore.

501. TENORITE; Black oxide of copper; is a valuable ore in many mines. It occurs in dull, black, earthy masses, soiling the fingers. It yields 60, 70, or even 80 per cent. of copper, and is considered to be a natural protoxide, but often contains sulphur, and is most likely the product of the decomposition of other ores. When found with other copper ores, there is little danger of mistaking this mineral. In other cases, as it resembles the oxides of manganese and cobalt, it may be distinguished by the colour given to the button of glass, obtained under the blow-pipe. In the present mineral it is emerald-green, in manganese violet, and in cobalt rich blue.

502. AZURITE; Blue carbonate of copper. A deep blue or azure-coloured mineral (Monoclinic H=3·5, SG=3·83), containing, carb. ac. 24, ox. copper 70, water 6; generally crystalline, but also amorphous. Found in beautiful crystals at Chessy in France, in Siberia, lately in South Australia, and elsewhere. When abundant it is valuable as an ore of copper.

503. MALACHITE; Green carbonate of copper (Monoclinic H=2·5, SG=4). Contains, carb. ac. 18·, deut-ox. copper 70·5, water 11·5. This beautiful ore, remarkable for its rich velvet-green colour, is probably in all cases an incrustation or deposit from aqueous solution. Till lately, it was only found abundantly in Siberia, at Nijny-Tagilsk, whence very large quantities have been obtained, and where the finer specimens are greatly valued as an ornamental stone. Within the last few years the mines of South Australia have proved extremely rich in the same kind of ore, and it is now worked commonly, and to great advantage for the metal. It may be recognised by its colour, which, however, resembles that of several salts of copper, lead, and uranium. Malachite may be distinguished by its silky texture, and its complete solution, with effervescence, in nitric acid.

BURATITE, Hydro-carbonate of zinc, copper, and lime.
MYSORINE, (*Cu C*) Anhydrous carbonate of copper.
ATACAMITE, Chloride of copper.
SULPHATO-CHLORIDE OF COPPER.
DIOPTASE, Silicate of copper, contains about 50 per cent. of oxide of copper.

504. CRYSOCOLLA; Hydro-silicate of copper. A bright or bluish-green, massive or earthy mineral, found in Siberia and America, containing from 40 to 53 per cent. of oxide of copper and 17 per cent. of water, and sometimes used as an ore. It is distinguished from malachite by its residuum after exposure to the action of nitric acid. *Velvet copper ore* is probably also a silicate.

505. BLUE VITRIOL, Sulphate of copper, occurs native with the sulphurets of copper as the result of decomposition. It is a soluble salt, and easily recognised by its nauseous metallic taste.

BROCHANTITE, Sub-sulphate of copper, insoluble. *Kœnigite* is identical.

506. The following phosphates and arsenates of copper are of no value in the arts. The arsenates give the garlic odour before the blow-pipe. The phosphates give no fumes, and exhibit the reaction of phosphoric acid.

LIBETHENITE, *Apherese*, Phosphate of copper (ox. copper 66·7, ph. ac. 28·7, water 4·3), probably amorphous with *Olivenite*.
PHOSPHORI-CALCITE, *Ypoleine*, Hydro-phosphate of copper (ox. copper 62·8, ph. ac. 21·7, water 15·5). *Trombolite* and *Pelocronite* are varieties.
OLIVENITE (Ox. copper 58, arsenic acid 21, water 20).
ERINITE (Ox. cop. 59·4, ars. ac. 33·8).
LICORONITE (Ox. cop. 36, ars. ac. 22·5, water 25).
APHANESITE (Ox. cop. 62·8, ars. ac., 27, water 7·5).
EUCHROITE (Ox. cop. 47·5, ars. ac. 34, water 19), *Copper froth* is a variety.
CONDURRITE (Ox. 60·5, ars. ac. 26, water 9).
COPPER MICA (Ox. cop. 58, ars. ac. 21. water 21).
VOLBORTHITE, Vanadate of copper.

SILVER.

507. This important and valuable metal is very widely distributed over the earth, and is found either native; in ores, combined with oxygen, sulphur, and chlorine; or with other metals, of which antimony, iron, arsenic, lead, copper, bismuth, and cobalt may be mentioned as the principal. The associated earthy minerals and rocks are granite and other porphyritic rocks, gneiss, and various metamorphic rocks, and occasionally limestones, sandstone, and shales, of different geological periods.

Silver is distinguished by its beautiful white colour and brilliant lustre, which does not readily tarnish on exposure, unless sulphurous vapours are present. When perfectly polished it reflects more light and radiates less heat than any other metal. Its specific gravity is 10·47. It is harder than gold, but softer than copper, and the addition of a small alloy of copper hardens it. Next to gold, it is the most malleable metal, and it has also great tenacity, a wire of

$\frac{1}{12}$th of an inch supporting nearly 200 pounds. It fuses at a white heat at the temperature of 1873° Fahr., and absorbs a large quantity of oxygen gas when kept long in a pure state, melted and exposed to the air. It has been beaten into leaves $\frac{1}{100000}$th of an inch in thickness, and drawn into wires finer than the human hair. It is flexible. It is acted on by nitric and sulphuric, but by no other, acids.

Silver is obtained chiefly from the sulphurets often in combination with antimony; and also from the chloride, and native silver. South America has supplied the largest part, although the mines of Saxony, Bohemia, Hungary, Spain, Norway, the Hartz, Austria, and Russia, as well as many in Asia, have yielded enormous quantities. It is estimated that the value of the silver raised annually amounts to more than 5,000,000 of pounds sterling.

The uses of silver are numerous and for the most part well known. In its pure state it is too soft for coin, plate, and other ornamental purposes, requiring an alloy of copper, by which it becomes much harder without material alteration of colour or other properties. The standard silver of British coin is an alloy of 18 dwt. of copper to 11 oz. 2 dwt. of pure silver: the pound troy of 12 ounces being coined into 66 shillings. In the arts silver is employed in silvering or *plating* other metals either by a thin coating of the solid metal, by solutions of silver, or by the process of electrotyping. The oxide of silver is used in giving a yellow colour in porcelain painting—the nitrate is used in surgery as a caustic, and mixed with alcohol it forms a fulminating powder used in the preparation of percussion caps, lucifer matches, &c. The iodides and nitrates of silver are important ingredients in the processes of Daguerreotype and Calotype.

NATIVE SILVER is generally combined with from 10 to 15 per cent. of copper or bismuth, and is often crystallised in octahedrons. *Native amalgam* is a combination of mercury with silver, already alluded to, and represented by the formula $AgHg_2$. *Arquerito* is another combination, and consists of Ag_6Hg. It has been regarded as native silver, and is much worked in the rich mines of Arqueros in Chili. It is malleable. SG=10·85.

AURIFEROUS NATIVE SILVER.

ANTIMONIAL SILVER (Ag_2 Sb). An ore accompanying arsenical ores of silver, but not abundant enough to be worked.

ARSENICAL SILVER (AgF_2As, the iron being regarded as isomorphous with silver) A rich ore very variable in its yield of silver; silver white, brittle, yielding readily the garlic odour. Sometimes valuable as an ore.

MOLYBDIC SILVER.

508. VITREOUS SILVER; Sulphuret of silver. (AgS, H=2·5, SG =6·9—7·2.) The richest and most abundant ore of silver. Found crystalline, branching, or dendritic, and amorphous; malleable; rea-

dily fusible. Colour lead or steel-grey; easily tarnished. It resembles the grey sulphuret of copper, but is easily distinguished by its specific gravity. It contains, when pure, 86·5 per cent. of silver.

509. BRITTLE SILVER ORE; *Black silver, Sprödglaserz* ($H=3·5$, $SG=5·9-6·9$). Sulphuret of silver and antimony, copper and arsenic sometimes replacing the silver. A very important ore in the South American mines. Specimens have been found to contain from 66 to 68 per cent. of silver, and others containing somewhat more silver, and some arsenic, have been named *Polybasite.* The specific gravity is the best test of this, as of the preceding ore.

SULPHURET OF SILVER AND ANTIMONY, *Schilfglaserz* (silver 22·93, lead 30·27, antimony 27·38, sulphur 18·74).

FLEXIBLE SULPHURET OF SILVER, Sulphuret of silver and iron. It is very soft, yielding readily to a knife.

STERNBERGITE, Sulphuret of silver and iron ($Ag\ S_2+4\ FS$).

SULPHURET OF SILVER AND COPPER.

510. RUBY SILVER ($3AgS+Sb_2S_3$, $H=2-2·5$, $SG=5·72-5·84$). An abundant ore of silver in Mexico, and found in Saxony. Easily distinguished by its brilliant cochineal colour and red streak. It is transparent or translucent. It yields nearly 60 per cent. of silver. There are two varieties, one dark and the other light red, the former combined with about 20 per cent. of antimony, and the latter with 15 per cent. of arsenic.

PROUSTITE ($3\ Ag\ S+As_2\ S_3$).

MIARGYRITE, Antimonial sulphuret of silver.

SELENIURET OF SILVER ($Ag\ Se$).

511. HORN SILVER; Chloride of silver. ($AgCl_2$, $SG=5·27$.) Contains, when pure, 68 to 76 per cent. of silver. A soft mineral, of grey, green, or bluish colour; cutting like wax or horn. Readily known by its softness, and much worked in South America and Mexico, especially at Potosi.

IODIC SILVER (Ag_2I).

BROMIC SILVER ($Ag\ Br_2$).

CARBONATE OF SILVER ($Ag\ C_2$).

GOLD.

512. Gold is found only native, and rarely pure, being generally alloyed with silver, and frequently with copper, palladium, and osmium. It always presents the peculiar yellow character which belongs to it, and takes a very brilliant polish. Its hardness is inferior to that of silver, but greater than tin and lead. It is the most malleable and, with the exception of iron, the most tenacious metal. Its specific gravity is very high (amounting to 14·857 for pepitas, and as much as 19·258 when hammered). It is fusible at a temperature of 2016° Fahr., but is unaltered by exposure. Beaten into thin leaves it is transparent, and transmits light of a beautiful green colour. It also appears of brilliant greenish colour when in fusion.

Gold has been formed into wire of the diameter of only $\frac{1}{5000}$th of an inch, 550 feet of it weighing only 1 grain. It has been beaten into leaves only $\frac{1}{280000}$th of an inch in thickness. It expands more than any other metal when fused. It is unaffected by any of the simple mineral acids, but dissolves in nitro-muriatic acid.

Gold occurs in crystals; in dendritic and branching fragments; in filaments, grains, and minute flat spangles; and also in lumps or pepitas. It is rarely obtained with profit from the veins in which it has been originally formed, and is chiefly procured from gravel and detritus, together with which it has been removed by the action of water from its original position in rocks. *Electrum* is a variety, containing a large proportion of silver, which seems to replace and be isomorphous with the gold. The palladium-gold, or *Jacotinga* of Gongo Soco in Brazil, is another variety, and there is also found occasionally another mixture of gold and palladium, and an alloy of gold with rhodium.*

The uses of gold are numerous, and for the most part well known. Alloyed with one 11th part by weight of copper or silver, it is used in this country as a coin, being then much harder than in its pure state. With a still larger admixture of other metal, it is very extensively used in jewellery. In consequence of its extreme divisibility and malleability, it is used in gilding or coating other substances with an exceedingly thin film, which is very durable, owing to the perfect manner in which it resists oxidation from exposure. Some of the salts of gold are used in porcelain painting.

The rocks in which gold is found are very variable, including granites, slates and schists, and even limestones. The alluvial deposits containing particles of the metal, and most prolific when sifted and washed, are quartzy sands with iron. It has been considered that the sand of any river pays for washing if it yield on an average 24 grains of gold per hundred weight of sand.

The chief localities in which gold is worked to profit are, 1. the Ural mountains and the adjoining district of Siberia; 2. the upper part of California, only recently found to produce this valuable metal in abundance, but promising a large supply; 3. Brazil; 4. Central and Western Africa, the exact localities being unknown; 5. the East Indian Islands; and, 6. Bohemia and Transylvania. The total annual supply, on an average of several years, does not exceed 40 tons, its value being about 5,000,000 sterling; but during the past year (1849), more than 10 tons have been reduced in London from the recently discovered gold-washings of California.

Masses of gold of considerable size have been found from time to time; several specimens weighing as much as 16 pounds troy, one of

* The author endeavoured to collect and arrange in a useful form the various facts relating to the distribution of gold, in a little work ("The Gold Seeker's Manual"), published at the commencement of the year 1849.

27 pounds, and one, discovered in 1842, weighing nearly 100 pounds troy. These are all from the Ural; but other large masses have been reported from the province of Quito weighing 50 and 60 pounds.

Auro-tellurite and *Graphic tellurium* are ores of tellurium, chiefly valuable for the gold they contain. The latter contains 30 per cent. of gold.

It may be useful to mention that the English sovereign contains 123·274 grains troy of gold, 22 carats fine, and therefore 113·001 grains of fine gold. Thus the ounce troy of fine gold is worth 4*l.* 4*s.* $11\frac{1}{4}\frac{5}{6}$*d.*, nearly, and the ounce of standard gold, being 1-12th less, amounts to 3*l.* 17*s.* $10\frac{1}{2}$*d.* The French Napoleon weighs 99·564 grains, of which 89·61 are fine gold. The Dutch 10 florin piece weighs 103·88 grains, and the American eagle 269·85 grains, of which 232 are fine. The pound troy of standard gold is coined into $46\frac{89}{120}$ English sovereigns, and the pound avoirdupois of fine gold is worth 61*l.* 18*s.* 11*d.*

PLATINUM.

513. This rather remarkable metal, of whitish iron-grey colour and extreme specific gravity (rising to 21·53 in purified and prepared specimens), is distributed, like gold, in grains or pepitas, and obtained from the sands of valleys opening out from crystalline rocks. It cannot be melted by the heat of the fire, but admits of welding in the manner already described for iron (§ 449). Its hardness is 4 – 4·5, and it is scratched by iron. It is usually combined with palladium, rhodium, iridium, and osmium, besides copper and iron. The malleability of platinum is very considerable, as it may be beaten into leaves as thin as tin-foil. Its ductility is however far more remarkable, as Dr. Wollaston obtained a wire not more than $\frac{1}{30000}$th of an inch in diameter. Its tenacity is very great, as the same chemist found that a wire of $\frac{1}{18750}$th of an inch will support a grain and a third without breaking. Except Tantalum it is the most infusible of all metals. It is very slightly magnetic. In thin plates it is ductile and flexible.

Platinum is found (always in the metallic state) in Brazil and Peru, in Spain, and in the Ural Mountains. The particles are generally small and rarely larger than a pea, but a mass has been found weighing 20 pounds.

It is of great value in the manufacture of utensils and instruments required to resist oxidation, and the action of acids and mercury, at very high temperatures. It is however not very plentiful. Coins have been made of it in Russia.

IRIDIUM.

514. A metal which has been rarely applied to any use. It is found with the ores of platinum in the washings of two localities in the Ural. The specimens found are generally mixtures or alloys of this metal and another, equally rare, named OSMIUM. Iridium is

extremely hard, and its specific gravity is 18·68. It is brittle, of whitish colour, and when carefully polished resembles platinum. It is scarcely affected by acids but forms several oxides and chlorides, and combines readily with carbon. It is infusible in the heat of a smith's forge, but may be melted before the oxy-hydrogen blow-pipe. It appears to be one of the metals that do not decompose water. The name is derived from the variegated colours (*iris*, a rainbow) of its solutions.

OSMIUM.

515. Osmium is a dark-grey or blue metal, infusible except before the oxy-hydrogen blow-pipe, and having a specific gravity of 19·5 (?). It is usually found alloying platinum. Its peroxide is extremely volatile and has a pungent odour. It has not been applied to any useful purpose.

Osmiridium is a natural alloy of Osmium and Iridium.

RHODIUM.

516. This metal is very rare, and is often, when found, associated with the native platina of Peru. It gives hardness to steel, and in the proportion of 1 to 2 per cent. might be alloyed with that metal to some advantage if it were more abundant. Like Iridium, it has been used instead of gold to manufacture the nibs of metallic pens. It is of whitish colour, difficult of fusion like Iridium, and extremely hard and durable. SG=10·65. The name is derived from the red colour (*rhodon*, a rose) of some of its salts.

PALLADIUM.

517. A metal not at present much used, but more abundant than either of the preceding. It is extracted from the auriferous sands and platinum of Brazil. It greatly resembles Platinum in colour, and has a splendid steel lustre when polished. It is malleable and ductile; very flexible when in thin laminæ, but not very elastic. SG=11·3—11·8. Somewhat harder than bar iron and about equal to fine steel. Fuses with great difficulty at the highest heat of a smith's forge. It is acted on by nitric acid, but resists ordinary exposure without tarnish. It has been used in the manufacture of some philosophical and surgical instruments.

Native Palladium occurs in grains apparently composed of diverging fibres, but in other respects these grains differ little in external character from those of the native platina among which they are found. It melts easily with the addition of sulphur, and forms a deep red solution with nitric acid.

APPENDIX.

ANALYSES OF IMPORTANT MINERALS.

TABLE I.

SILICATES CONTAINING ALUMINA.

Mineral.	Silica.	Alumina (Glucina)	Lime (Magnesia).	Potash or Soda.	Iron oxides (Manganese oxide).	Water.
1. Cyanite	36·67	63·11	....	....	1·19	
2. Garnet, No. 1	38·30	21·20	31·25	....	6·50	
3. Do. No. 2 ..	39·62	19·30	3·28 2·00 *Mg*	....	34·05 0·80 Mn	
4. Do. No. 3 ..	37·55	....	26·74	....	31·35 4·78 Mn	
5. Do. No. 4 ..	35·00	14·25	....	....	14·00 35·00 Mn	
6. Epidote	33·50	15·00	14·50	....	19·50 12·00 Mn	
7. Iolite	50·25	32·42	10·85 *Mg*	....	4·00 0·68 Mn	
8. Emerald	66·45	16·75 15·50 *Gl*	....	....	0·60	
9. Felspar, No. 1	65·91	21·00	0·11	10·18 *K* 3·50 *Na*		
10. Do. No. 2 ..	66·60	18·50	1·09 *Mg*	8·00 *K* 4·00 *Na*		
11. Phonolite....	57·66	19·96	1·01 1·53 *Mg*	6·06 *K* 6·98 *Na*	3·42 0·75 Mn	2·33
12. Albite	67·99	19·61	0·66	11·12 *Na*	0·70	
13. Leucite	53·75	21·63	....	21·35 *K*		
14. Mesotype ..	48·17	26·51	....	16·12 *Na*	....	9·17
15. Stilbite	58·00	16·10	9·20	....	....	17·40
16. Chlorite	31·47	16·67	32·56 *Mg*	....	5·97	12·43

No. 1 is from the St. Gotthard, by Rosales. No. 2, an *Essonite*, from Ceylon, by Klaproth. No. 3, a precious garnet (*Almandine*) from the Zillerthal, by Kobell. No. 4, a *Melanite*, of red colour, from Lindbo, by Hisinger. No. 5, a *Spessartin*, or manganesian garnet, from Spessart, by Klaproth. No. 6, a violet or manganese *Epidote*, by Cordier. No. 7, a specimen from Fahlun, by Stromeyer. No. 8, a *Beryl*, from Siberia, by Klaproth, containing 15·50 per cent. of Glucina. No. 9, a yellowish white variety from the Ural, by G. Rose. No. 10, a *Glassy felspar*, from the Drachenfels, by Berthier. No. 11, is a mean of six analyses, from various localities, by Gmelin. No. 12, a specimen, from Finland, by Tengström. No. 13, a crystal, from Somma (Vesuvius), by Klaproth. No. 14, a specimen from Auvergne, by Fuchs. No. 15, a specimen from Desmine, by Moss. No. 16, from the Zillerthal, by Kobell. Where no other base is mentioned, Alumina is understood in the second, Lime in the third, and Iron in the fifth column.

TABLE II.

NON-ALUMINOUS AND OTHER UNMETALLIC SILICATES.

Mineral.	Silica.	Magnesia (Lime).	Alumina (Zirconia).	Potash, Soda, Lithia.	Metallic oxides, (various).	Various Substances.
17. Talc	63·00	33·60	....	....	....	3·40 *Aq*
18. Steatite ..	63·95	28·25	....	....	0·60 Fe	2·71 *Aq*
19. Serpentine	41·95	40·64	0·37	....	....	11·68 *Aq*
20. Olivine ..	40·09	50·49	0·19	....	8·17 Fe 0·20 *Mn* 0·37 Ni	
21. Zircon ..	32·60	....	64·50 *Zr*	....	2·00 Fe	
22. Hornblende No. 1.	60·10	24·31 12·73 *Ca*	0·42	....	1·00 Fe 0·47 Mn	0·83 HF 0·15 *Aq*
23. Do. No. 2	42·24	13·74 12·24 *Ca*	13·92	....	14·59 Fe 0·33 Mn	
24. Augite, No. 1	54·64	18·00 24·94 *Ca*	....	....	1·08 Fe 2·00 Mn	
25. Do. No. 2	53·55	15·25 22·21 *Ca*	0·14	....	8·14 Fe 0·73 Mn	
26. Do. No. 3	48·70	9·90 14·60 *Ca*	1·60	....	20·30 Fe	2·20 *Aq*
27. Diallage ..	53·71	17·55 17·06 *Ca*	2·82	....	8·08 Fe, Mn	1·04 *Aq*
28. Topaz	35·52	....	55·14	....	....	17·21 F
29. Mica, No. 1	41·00	18·86	16·88	8·76 *K*	4·56 Fe 5·86 *Fe*	4·30 *Aq*
30. Do. No. 2	36·54	0·93 *Ca*	25·47	5·48 *K*	27·06 Fe 1·02 *Mn*	2·70 F
31. Tourmaline, No. 1	37·80	1·42	30·56	2·09 *Na*	12·07 0·50 *F* 2·50 Mn	9·90 *B*
32. Do. No. 2	39·70	0·16	40·29	7·88 *Na* 3·02 *L*	2·30 *Mn*	6·65 *B*
33. Lapis lazuli	35·80	3·10 CaC_2	34·80	23·20 *Na*	....	3·10 S
34. Spinelle ..	2·02	26·21	69·01	....	0·71 F 1·10 Cr	

No. 17 is from the Zillerthal, by Beudant. No. 18, from near Abo, by Tengström. No. 19, *Noble serpentine*, from Fahlun, by Lichnell. No. 20, *Basaltic olivine*, from the Vogelsgebirge. No. 21, from Ceylon, by Vauquelin. No. 22, *Tremolite*, from Fahlun, by Bonsdorff. No. 23, an aluminous hornblende, from Vogelsberg, by Bonsdorff. No. 24, a *Malacolite*, from Finland, by H. Rose, belonging to a group nearly colourless. No. 25, a green *Baikalite*, by H. Rose, belonging to a green group. No. 26, *Asbestus*, from the Little St. Bernard, by Berthier. No. 27, *Schiller-spar* (greenish colour), from the Hartz, by Köhler. No. 28, *Topaz* from Saxony, by Forchhammer. No. 29, *Uni-axal mica*, by Kobell. No. 30, *Bi-axal mica*, from Cornwall, by Turner. No. 30, a brown variety (*Schorl*), from Mursinsk, Russia, by Rammelsberg. No. 31, a specimen of noble tourmaline or *Rubellite*, from the same locality, and by the same chemist. No. 33, is by Clement and Desormes, and is considered as representing the true composition of the mineral. No. 34, *Spinelle ruby*, by Abich. In the fifth column, when Roman characters are used, the protoxides of the metals are meant; when italic, the peroxides.

TABLE III.

METALLIC SILICATES.

Mineral.	Silica.	Oxide of principal Metal.	Various metals.	Various earthy bases.	Water.
35. Cerite	18·00	68·59 Ce	2·00 Fe	1·25 *Ca*	9·60
36. Manganese spar..	48·00	49·04 Mn	....	{ 3·12 *Ca* 0·2 2 *Mg*	
37. Jenite	29·83	{ 32·70 Fe 22·85 *Fe* }	1·51 *Mn*	12·43 *Ca*	
38. Chamoisite	14·30	60·50 Fe	....	7·80 *Al*	17·40
39. Electric Calamine	24·89	66·83 Zn	....	0·81 *P*	7·50
40. Sphene	32·29	41·58 *Ti*	1·07 Fe	26·61 *Ca*	
41. Bismuth blende..	22·23.	69·38 Bi	{ 2·40 Fe 0·30 M }	3·31 *Ph*	1·01
42. Crysocolla	26·00	41·80 Cu	2·5 Fe	3·70 *Ca*	23·50

No. 35 is an analysis by Hisinger. No. 36, a lamellar variety by Berzelius. No. 37, the mean of several analyses by Rammelsberg. No. 38, from Chamoisin, by Berthier. No. 39, a variety from Limbourg, by Berzelius. No. 40 is from Zillerthal, by H. Rose. No. 41, is by Kersten. No. 42, from Cornwall, by Berthier.

In this and subsequent tables the peroxide is meant where the symbol is printed in italics.

TABLE IV.

METALLIC CARBONATES.

Mineral.	Oxide of the principal Metal.	Carbonic acid.	Salts of various other metals.	Various bases.	Water.
43. Diallogite	50·96 Mn	31·24	7·3 *FeC*	{ 8·9 *CaC* 1·6 *MgC*	
44. Spathic iron	50·41 Fe	38·64	7·51 MnO	{ 2·35 *Mg* 0·32	
45. Do.	43·82 Fe	26·18	....	{ 23·00 C 7·	
46. Calamine	61·92 Zn	34·18	{ 2·03 *FeC* 1·12 *PbC*		
47. White lead ore ..	82·00 Pb	16·00	2· Fe		
48. Malachite	70·50 Cu	18·00	....	....	11·50

No. 43, is from Freiberg, by Berthier. No. 44, a crystalline variety from Hachenburg (Nassau), by Karsten. No. 45, a clay ironstone, from the Black band of Lanarkshire. Amongst the various bases are included silica, alumina, and some lime. The carbon is not pure. No. 46 is a pure variety from Nertschinsk, by Kobell. No. 47 is from Leadhills, by Klaproth. The iron includes also alumina. No. 48 is a green compact variety from Turjinsk, by Klaproth.

TABLE V.

METALLIC OXIDES.

Mineral.	Principal metal.	Oxygen.	Other metals.	Earthy bases.	Water.
49. Pyrolusite	61·80 Mn	35·42	....	{ 0·66 *Ba* 0·55 *Si* }	1·57
50. Wad	57·72 Mn	30·23	....	1·40 *Ba*	10·66
51. Magnetic iron ore	68·38 Fe	26·54	2·00 *Mn*	2·68 *Si*	
52. Red Hæmatite ..	63·62 Fe	26·72	9·66 *Ti*		
53. Brown Hæmatite	55·00 Fe	24·30	4·00 *Mn*	2·60	13·70
54. Chrome ochre ..	68·65 Cr	31·35			
55. Earthy cobalt ..	22·75 Co	16·06	31·21 *Mn*	....	22·90
56. Red zinc	75·04 Zn	18·46	{ 0·40 *Fe* 5·50 *Mn*		
57. Arsenite	75·76 As	24·24			
58. Rutile	58·85 Ti	38·75	2·40 *Fe*		
59. Minium	90·70 Pb	9·30			
60. Tin ore	77·50 St	21·50	0·25 *Fe*	0·75 *Si*	
61. Pitchblende	65·96 U	13·19	{ 3·03 FF. 6·20 Pb 1·13 As 0·65 Bi	2·81 *Ca* 0·46 *Mg* 5·30 *Si* }	0·36
62. Molybdic ochre ..	65·71 Mb	33·40			
63. Red copper ore ..	85·50 Cu	11·50			
64. Tenorite	78·83 Cu	20·07			

No. 49 is from Devonshire, by Turner. It contains 11·6 per cent. of oxygen in excess. No. 50 is also from Devonshire, by Turner, and contains 8·82 per cent. oxygen in excess. No. 51, a foliated variety, from Arendal, Sweden, by Kobell. No. 52 is a variety from the St. Gotthard, by Kobell. The titanium is considered to be titanic acid. No, 53 is an earthy hydrate of iron by Beudant. No. 54 is the chemical composition of the oxide, which is, however, rarely pure. No. 55 is a variety from Saalfeld, by Döbereiner, in which there is 6·78 oxygen in excess. The analysis can hardly be expected to be the same for any two specimens. No. 56, a variety by Hayes. No. 58 is by Kersten. No. 60 by Klaproth. No. 61, from Joachimsthal, by Rammelsberg.

Many of the ores, of which analyses are given in the above table, are of considerable importance, but very few are presented commonly in nature in a pure form. A reference to the text will show which of them are valuable ores, and it will be explained in a future chapter how widely spread are the combinations of oxygen with metallic bases. On the whole, it may be considered that the oxides and sulphurets afford the principal portion of the various metals used in the arts.

TABLE VI.

METALLIC SULPHURETS.

Mineral.	Principal metal.	Sulphur.	Various other metals.	Various other substances.
65. Manganese blende..........	62·10 Mn	37 90		
66. Iron pyrites	47·30 Fe	52·70		
67. Magnetic pyrites	59·85 Fe	40·15		
68. Arsenical pyrites	34·94 Fe	20·13	43·42 As.	
69. Cobalt pyrites	43·20 Co	38·50	14·40 Cu 3·53 Fe	0·33
70. Nickel pyrites	61·34 Ni	35·79	1·73 Fe 1·14 Cu	
71. Bismuth nickel	40·65 Ni	38·46	14·11 Bi 3·18 Fe 1·68 Cu 1·58 Pb 0·28 Co	
72. Blende	61·50 Zi	33·00	4·00 Fe	
73. Greenockite	77·55 Ca	22·41		
74. Grey antimony	73·77 Sb	26·23		
75. Berthierite................	54·70 Sb	31·33	11·43 Fe 2·54 Mn 0·74 Zn	
76. Realgar	69·57 As	30·43		
77. Orpiment	61·86 As	38·14		
78. Cinnabar	85·00 Hg	14·25		
79. Galena	83·00 Pb	16·41	0·08 Ag	
80. Bournonite	39·00 Pb	16·00	28·50 Sb 13 50 Cu 1·00 Fe	
81. Vitreous copper ore	78·50 Cu	18·50	2·25 Fe	0·75 Si
82. Copper pyrites	31·20 Cu	34·46	30·80 Fe 2·44 Pl, As	1·10 Si
83. Grey copper ore (Fahlerz) ..	37·98 Cu	25·77	23·94 Sb 0·62 Ag 0·86 Fe 2·88 As 7·29 Zn	
84. Silver Fahlerz	25·23 Cu 17·71 Ag	23·52	26·63 Sb 3·72 Fe 3·10 Zn	
85. Vitreous silver	86·39 Ag	13·61		
86. Brittle silver ore	68·54 Ag	16·42	14·68 Sb 0·64 Cu	
87. Ruby silver	58·95 Ag	16·61	22·85 Sb	0·30 Si

No. 65 is by Arfvedson. No. 66, by Hatchett. No. 67, by Stromeyer. No. 68 by M. Chevreul. No. 69, from Bastnaes, by Hisinger. No. 70, from Camsdorf, by Rammelsberg. No. 71, by Kobell. No. 72, lamellar varieties from England, by Berthier. No. 73, by Jameson. No. 74, from Scotland, by Thompson. No. 75, from Braunsdorf, by Rammelsberg. No. 76, 77, by Laugier. No. 78, from Carniola, by Klaproth. No. 79, a specimen from Hanover, by Westrumb. No. 80, a variety

from Cornwall, by Klaproth. No. 81, from Katharinenberg, by Klaproth. No. 82, a botryoidal variety from Cornwall, by Phillips. No. 83, a crystalline specimen from Hungary, by H. Rose. No. 84, from Wolfach, in the Black Forest, also by H. Rose. No. 85 from Joachimsthal, by Klaproth. No. 86, from Chemnitz, by H. Rose. No. 87, from Andreasberg, by Bonsdorff.

TABLE VII.

VARIOUS METALLIC SALTS.

Minerals.	Principal metallic and other base.	Principal combining substance.	Metallic impurities.	Earthy impurities.	Water.
88. Psilomelane....	51·22 Mn	26·28 O	....	16·50 *Ba* 2·00	4·00
89. Chromic iron	30·44 *Fe* 12·22 *Al*	52·95 *Cr*			
90. Vivianite......	43·78FeO	30·32 *P*	....	0·70 *Al* 0·03 *Si*	25·00
91. Pharmacosiderite	39·20 *Fe*	37·82 *As* 2·53 *Ph*	0·65 CaO	....	18·61
92. Copperas......	25·70 FeO	28·80 *S*	....	....	45·40
93. Cobalt bloom ..	36·52 *Co*	38·43 *As*	1·01 FeO		23·10
94. Nickel green ..	36·20 *Ni*	38·30 *As*	1·53 *Co* trace Fe	....	23·91
95. Tungsten......	18·70 *Ca*	75·25 *W*	1·25 *Fe* 0·75 Mn	1·50 *Si*	
96. Pharmacolite ..	25·00 *Ca*	50·54 *As*	....	....	24·46
97. White vitriol ..	28·50 ZnO	29·80 *S*	0·70 *Fe* 0·40 *Mn*	....	40·80
98. Horn quicksilver	85·11 Hg	14·89 Cl			
99. Anglesite......	71·00 PbO	24·80 *S*	1·00 *Fe*	....	2·00
100. Pyromorphite	56·62 PbO 7·50 Pb	32·49 *Ph* 2·57 *Cl*	....	0·68 *Ca Ph* 0·13 CaF	
101. Crocoisite......	68·50 PbO	31·50 *Cr*			
102. Molybdate of lead	58·40 PbO	37·00 *Mb*	3·08 *Fe*	0·28 *Si*	
103. Uranite	61·73 *U*	15·20 *Ph*	0·06 SnO	5·88 *Ca* 1·57 *Ba*	15·48
104. Vanadinite ..	66·33 PbO 7·06 Pb	23·43 *V*	0·16 *Fe*	2·45 Cl H	
105. Libethenite	63·90 CuO	28·70 *Ph*	....	....	7·40
106. Horn silver	67·75 Ag	27·50 Cl	6·00 Fe	1·75 Al 0·25 *S*	

No. 88 is from Romaniche, by Berthier. No. 89, a crystallized specimen from Baltimore, by Thompson. No. 90, a compact earthy variety from Hillentrup, by Brander. No. 91, by Berzelius. No, 93, 94, from near Schneeberg, by Kersten. No. 95, from Pengilly, Cornwall, by Klaproth. No. 96, from Swabia, by Klaproth. No 97, from Schemnitz, by Beudant. No. 98, by Berzelius. No. 99, from Anglesea, by Klaproth. No. 100, an English specimen, by Kersten. No. 101, by Berzelius. No. 102, from Bleistadt, by Hatchett. No. 103, from Autun, by Berzelius. No. 104, Wicklow (? or Wanlockhead), by Thompson. No. 105, from Libethen, by Berthier. No. 106, from Saxony, by Klaproth.

TABLE VIII.

VARIOUS METALLIC MIXTURES AND ALLOYS.

Mineral.	Principal metallic base.	Principal combining metal.	Other metals.	Other substances.
107. Smaltine	20·31 Co	74·22 As	3·42 Fe 0·16 Cu	0·89 Su
108. Copper nickel ..	44·21 Ni	54·72 As	0·34 Fe 0·32 Pb Trace Co	0·40 Su
109. Antimonial nkl.	33·75 Ni	32·06 As 27·90 Sb	1·04 Fe	2·65 Su 2·00 *Si*
110. Graphic tellurium, or gold	30·00 Au 10·00 Ag	60·00 Te		
111. Arsenical antim.	37·85 Sb	62·15 As		
112. Native amalgam	25·00 Ag	73·00 Hg		
113. Arsenical copper	71·64 Cu	28·36 As		
114. Antimonial silver	76·00 Ag	24·00 Sb		
115. Arsenical silver	14·0 Ag	62·90 As	17·89 Fe	5·75 S
116. Electrum	64·00 Au	36·60 Ag		
117. Native platinum	73·58 Pt	2·35 Ir 1·15 R 0·30 Pd	12·98 Fe 5·20 Cu	0·60 Si
118. Platin-iridium ..	55·44 Pt	27·79 Ir 6·86 R 0·49 Pd	4·14 Fe 3·30 Cu	
119. Osmiridium	46·77 Ir	49·34 Os 3·15 R.	0·74 Fe	

Nos. 107 and 108, are from Reichelsdorf, by Stromeyer. The latter is extremely variable in different specimens. Several similar ores of nickel occur which we have not space here to enumerate; but the next, No. 109, is remarkable. The analysis is the mean of two by M. Berthier. No. 110, is by Klaproth. No. 111, from Allemont, by Rmmelsberg; but as the metals are isomorphous, there is no definite compound. No. 112, from Moschel-Landsberg on the Nahe, by Heyer. No. 13, from Chili, by M. Domeyto. No. 114, from Wolfach, by Klaproth. No. 115, from Andreasberg, by Dumenil. No. 116, from Schlangenberg, by Klaproth. No. 117, from Nijny Tagilsk, by Berzelius. In this analysis there was found in addition 2·30 per cent. of Osmium and Iridium in a state of combination. No. 118, from Brazil, by Svanberg, and No. 119, from Katharinenberg, in the Ural, by Berzelius.

ALPHABETICAL INDEX

OF THE MINERALS DESCRIBED IN THIS DIVISION OF THE WORK.

As a description of minerals is of comparatively little value without ready means of reference, the author has thought it advisable to append here an alphabetical index, by which the reader may at once find the paragraph at which any required mineral is referred to. This index includes about 1150 names, of which nearly seven hundred are synonyms, but, in the present state of mineralogical nomenclature, it seemed absolutely necessary to introduce this large number. Even now the index is by no means perfect, though sufficiently so for most practical purposes.

PART III.

DESCRIPTIVE GEOLOGY.

CHAPTER XI.

ON THE NATURE OF ROCKS, THE MODE OF THEIR ORIGINAL AGGREGATION AND SUBSEQUENT METAMORPHOSIS, AND THE DIFFERENT KINDS OF ROCKS THAT ARE FOUND NEAR THE EARTH'S SURFACE.

518. By the term rock, in Geology, is understood any aggregation of minerals, or fragments of minerals—whether crystalline or amorphous, hard or soft, compact or loose,—forming now an essential part of the mass of matter subject to our observation near the earth's surface. Rocks may, therefore, be mere mechanical heaps, presenting no structure, and nothing from which their history can be traced; or they may be mechanical heaps arranged so that we can readily discover the law of their formation; or finally, they may be so far modified by some re-arrangement of particles—the result of chemical action—that the history they present is that of subsequent change, more or less obscuring the evidence of original formation. The vast majority of examples are of the latter kind, and are often very difficult to comprehend, since few rocks are without marks of some action which has changed them from their original condition, and to determine how far this alteration is the result of desiccation, pressure, the attraction of cohesion, or time; and how much of it is due to chemical causation; has rarely been determined by geologists, and has formed but a small part of the objects of chemical investigation. In this chapter an attempt will be made to lay before the student an account of the actual condition of various rocks; but in doing so it will be necessary to introduce some views of the nature of such rocks which are not quite in accordance with those commonly entertained. Without, however, pledging the student to any opinions on the theoretical

part of the subject, it is very desirable that attention should be directed to such investigations, as having direct reference to the most pressing and important department of practical, as well as scientific, geology.

519. Rocks may be regarded in two ways, either as derived from certain crystalline masses, such as granite, presumed to be part of the original oxidized film of the earth before it became affected by atmospheric or aqueous agency, and thence called *Primitive*, *Endogenous*, or by other similar and significant names; or, as mineral substances accumulated at first in a manner more mechanical than chemical, and afterwards changed, by the action of chemical force, into the condition in which we now find them. The former view involves the idea that a large part of the surface has undergone little change, and that masses of rock remain, for an indefinite period of time, in a state of permanent equilibrium, so far as their internal and molecular arrangement is concerned. The latter view, without assuming that changes have really taken place in these respects, admits the possibility of their occurrence; and as it teaches us to proceed from the known to the unknown, and requires no statement of theory at starting, we shall here endeavour to carry the reader along, step by step, by its assistance, commencing with phenomena that we can explain distinctly, and advancing gradually to those concerning which we can only speculate.

520. The essential minerals in all natural combinations on a large scale, are Quartz, Limestone, Clay, and Water; and we must refer to the paragraphs where the three former have been described as minerals, for an account of their important chemical and mineralogical characteristics. We have, however, now to consider them in a somewhat different point of view, as amorphous masses, compounded generally of several substances, and admitting of many varieties of appearance and structure. In this form they abound everywhere, while the crystalline forms, unmixed with other substances, are so little abundant that we may safely regard them as rare exceptions to the general rule. The common varieties, the common associations, and the common modifications, are the materials for the geologist; and he often puts aside the crystalline mineral as an object of interest quite distinct from, and subordinate to, the amorphous, massive, or semi-crystalline rock. It must not, however, be concluded that the crystal and the mineral species are useless even to the geologist, for they often afford good evidence of change having taken place in the whole mass; and with such evidence it is of the greatest importance that he should be acquainted.

521. While the great mass of all rocks is made up of quartz, limestone, or clay, or admixtures of these, there are many other substances whose presence is not less invariable; although the proportion they

bear in point of actual quantity is often extremely small. Such ingredients may be regarded as of two kinds—those which are essential in giving to the various rock masses either their character of usefulness, or the marks by which they may be distinguished; and those whose presence is not easily recognised owing to the small proportion in which they exist, or which, if found, are not known to have any useful properties under the circumstances in which they appear. Among the first group Iron is the most remarkable, giving colour to almost every natural substance, and performing many parts in nature of infinite importance. The bases of various alkaline earths, and chiefly the salts of potash and soda, may be mentioned as present to almost equal extent and in nearly the same way. Carbon, Magnesia, Sulphur, and Phosphorus, among the solids; and Chlorine and Nitrogen among gases, complete the list of substances of this nature.

522. Of elements widely distributed, but whose value and necessity are not so manifest, Manganese, Gold, Arsenic, and Titanium, are well known metals: and Fluorine, Iodine, and Lithia, other substances also widely spread. Some of these, as gold, are of great value when obtained in sufficient quantity; but in the proportion in which they are found in most rocks, the cost of extraction would be very much more considerable than the value of the produce. Others, as Titanium, have no known value. We may regard the substances thus widely but not abundantly distributed, as more important in modifying than in forming rocks; and it is clear that when there is any possibility for chemical action to take place, the materials at first accumulated independently of each other, will soon begin to act on each other, and may in many cases produce combinations totally unlike those originally constituted.

523. We learn from the investigations of modern chemists, that new combinations may take place in solid bodies, without either substance being in a state of absolute fusion, or of aqueous solution. The passage of an electric current through moist clay, tends to produce an entire re-arrangement of the particles of the mass, giving to the whole a lamination which the original did not possess, and which has no reference to any original lamination of the mass itself; and also separating certain impurities, and collecting them into simple minerals in some crevice or cavity.

Amongst the evidence of this kind to which we can directly refer is that of Mr Robert Were Fox. This gentleman submitted a mass of moist clay worked up with acidulated water, to weak voltaic action for some months; and it was found at the end of that time, to exhibit when dry a rude laminated structure, the planes of the laminæ being at right angles to the electric forces. Mr. Hunt has also made experiments, extending these investigations to other substances with similar results.*

Besides this direct evidence with regard to rocks, there have also been observations

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* Mem. of Geol. Survey of Great Britain, vol. i. p. 451, and vol. ii. p. 631.

made by some distinguished chemists which, so far as they go, illustrate the same principle. Thus M. Mitscherlich, in experimenting on the sulphates of lime and other substances, found prismatic crystals of nickel distinctly modified, and the internal arrangement of the atoms changed, by a few days' exposure to the sun's rays, without the exterior being affected ; and Sir H. de la Beche has well observed in quoting this experiment, "When acquainted with these and other facts of the same kind, we are led to suppose that rocks may not only become visibly altered by the long-continued action of diminished or increased heat upon them, but that they may also have their various parts differently arranged, as to mutual attraction, without the general appearance of the rock being sensibly changed."* The same author adds, in another place, "Crystals of sulphate of zinc and sulphate of magnesia, gradually heated in alcohol, lose their transparency, and are found composed of numerous small crystals, differing in form from those used in the experiment." Mitscherlich has observed that the optical properties of plates of sulphate of lime and other substances were altered by changes of temperature ; showing an alteration in the interior structure while no sensible exterior modification could be observed in the plates. The various tempering of steel and the annealing of glass, must also arise from new arrangements of the particles of steel and glass caused by heat insufficient to produce fusion. If we take a piece of common green bottle-glass and expose it to continued heat, insufficient to cause fusion, we obtain a crystalline substance composed of numerous prisms arranged at right angles to the surfaces of the glass, the external form of which remains unaltered, notwithstanding the new arrangement of the internal particles.

524. Among the mineral substances present in most rocks in very small quantity, a considerable number are the same as those which are also found in organic bodies either animal or vegetable. We must in all cases suppose that the elements were originally obtained in some way from the mineral kingdom, but the reaction of the organic on the inorganic world has manifestly gone on so long as to render it very difficult to determine in each particular rock, whether certain substances present are, or are not, proximately due to organic causes. To give a single and familiar instance of the exact meaning of this, let us refer to such accumulations of coal as are now well known and universally admitted to be of vegetable origin. These consist chiefly of carbon, and the carbon thus obtained must have been derived either directly or indirectly from the mineral kingdom, although now so far as its origin can be traced, it partly exhibits organic structure, and is partly restored to what must be regarded as an inorganic state. So in other cases the accumulations of shells of marine animals, consisting of carbonate of lime, although inorganic so far as the present form of their existence is concerned, are clearly due to organic causation ; and so again the infusorial mud found embedded near the mouths of rivers, is an inorganic product due to the secretions of organic beings. It is, however, difficult to draw the line between that which is and that which has been organic.

525. As long as by direct evidence of any kind we can trace actual organization, as in the ashes of coal, the shape of a sea-shell or coral, or the siliceous skeleton of an animalcule, there is no difficulty in determining how these substances were introduced, and this is especially

* De la Beche's "Theoretical Researches," p. 106.

the case when the materials form part of regular beds, amongst which it is easy to suppose organic remains would be found. Thus in the mud, sand or silt of rivers, or in the accumulations of broken material near a coast, no one would be surprised to find twigs, leaves, broken shells, fishes teeth, and other matters of the kind; but when we discover, as has been lately done, that the remains of animals resembling those inhabiting the land and fresh-water are thrown up into the air, as volcanic products, from islands without fresh-water in the middle of a great ocean, some astonishment may well be felt, although the fact seems equally beyond question. When, however, salts of potash and soda, together with phosphorus, carbonate of lime, and other substances, are the only evidences of the former existence of animals and vegetables, it is by no means an easy matter to decide how far the presence of a certain excess of minerals, usually or always rare, is indicative of organic origin, or refers to a condition of the earth before animals and vegetables existed on its surface.

526. Geologists have generally agreed to speak of the various rocks presented to their notice, as separable into three groups. These have been named respectively, MECHANICAL, METAMORPHIC, and CRYSTALLINE; or AQUEOUS, METAMORPHIC and IGNEOUS: the term *Metamorphic* indicating an intermediate state not very distinctly limited in its meaning. The Mechanical or aqueous rocks are understood to include all the ordinary sandstones, limestones, and clays, or mixtures of these, which appear to have been deposited from water, and which show lamination, or as it is called, *stratification:* and on the other hand, the Crystalline or igneous group comprehends certain mineral masses, of which granite is a familiar example, which are found in many districts, and in which marks of mechanical deposit cannot generally be traced. We shall have to recur frequently to these terms, which are too firmly rooted in the scientific language of the day to be neglected or disturbed; but as, in fact, there is hardly one of the infinite variety of accumulations of mineral matter at the earth's surface which is not *metamorphic* in the strict sense of that term, we do not willingly admit a distinction which is certainly not of Nature's making.

The only way in which we can obtain a satisfactory notion of the different groups of rocks seems to be by referring each, as far as possible, to its origin as a mechanical aggregate, and then tracing the various transformations or metamorphoses which each may undergo when exposed to such chemical action as we can fairly assume. This mode of treatment has at least the advantage of distinctness, and the student will thus see as he advances the bearings of the subject, and also recognise its weak points as well as its strength.

An idea will at the same time be communicated of the influence of organic products, and of the use of their study in the higher problems of Geology altogether distinct from that usually afforded, which has

reference only to the determination of the relative date of formation of certain similar mineral masses.

It is not difficult to recognise three divisions, to some one of which a very large number of rocks may be referred ; these divisions having reference to the mineral ingredient which forms the characteristic in each case. We may call them, *the sand group, the lime group*, and *the clay group* respectively, and we purposely avoid any more accurate definition at present, in order that they may be more readily understood and more generally inclusive. We will now mention the principal conditions occurring in each of them, in the order of their occurrence in nature, so far as we can trace it.

The Sand Group.

527. The simplest mechanical condition of the rocks referred to this group is that of fine white sand, the particles being small, of uniform size, and consisting of nearly pure quartz. Such material is not unfrequently seen by the sea-side, and it is there found to be absorbent of water, becoming then compact and even hard, admitting readily of impressions upon its surface, and retaining them for some time. Such material also occurs not unfrequently alternating with clays, and if met with in sinking a shaft or making a cutting, readily gives out the water it contains, and, from its loose texture, is soon removed. It is then called quick-sand.

If we take up an ordinary piece of white sandstone, and compare it with this loose sand, some differences will be recognised, and we thus are introduced to the first and simplest modification of a rock. The particles of sand have now been consolidated, and a texture is observable which may be fine or coarse according to the size of the component particles, and loose or compact according to the way in which it has become solidified. The process of consolidation thus induced may be merely the result of the force of cohesion, for no doubt the continued contact of the particles under heavy pressure may produce such change ; but the infiltration of water containing the small quantity of silica usually present in sea-water, or of a little clay, lime, or iron, also found there in small quantities, is often the immediate cause of this consolidation, while a little carbon or bitumen frequently points to organic agency.

528. Loose sand exposed for a long time to great heat without pressure, as at the bottom of a furnace, will sometimes consolidate and form a compact and very durable but brittle stone. It is difficult generally to avoid the presence of a small quantity of alkaline earth, which serves as a flux ; but examples have been often obtained of pure sand forming into a loose rock with a coarsely columnar structure. This seems to be a first approach to crystallization, and is generally assumed by rock masses when circum-

stances are favourable, that is, when they have long been exposed to uniform conditions of pressure and temperature; a high temperature not being required.

An interesting example of the effect of continued heat upon the sand made use of to line the inside of a reverberatory furnace has fallen under the author's observation, a specimen having been sent to King's College for examination. The sandy floor was originally of perfectly loose texture and of a deep red colour (owing to the presence of oxide of iron). Its thickness amounted to several inches. After having been for about a fortnight at the bottom of the furnace, the part nearest the fire became of a black colour and a loose scoriaceous texture, but at a very little depth the scoriaceous appearance ceased, and there was found a considerable thickness of compact, close-grained sandstone without colour, exhibiting a distinctly columnar structure. Below this the sandstone gradually passed again into loose red sand as the effect of the heat had been less felt.

529. The most compact form of sand rock is that denominated *quartz rock*, or *quartzite*. We quote the following account of its general characters from Dr. Macculloch. "It is occasionally, but rarely, found in a compact state and crystalline throughout; little differing from quartz as it occurs in veins; but even in these cases showing a constant tendency to divide in parallel beds. More generally, when pure, it has an aspect obscurely granular, which by degrees becomes somewhat lax and arenaceous; the grains varying in size and in the intimacy of their union. In some of these examples, it appears to be a granular crystallized mass; in others, it possesses a mixed mechanical and chemical texture; while, in a third, the rounded aspect of the grains, and the small number of the points of contact, appear to indicate an origin chiefly mechanical, and resulting from the agglutination of sand. These are its varieties when in the purest state, and, I may add, that cavities are sometimes found in the specimens, containing regular although minute crystals."*

The rock thus characterized is considered as primitive, but from the account given and the specimens usually obtained, it appears that the transition from the granular to the crystalline state is so gradual as to justify the idea that the one is but an altered form of the other.

530. Beside these three varieties of pure sand rock, there are, however, innumerable others presented in nature, where the sand is associated with clay, calcareous matter, iron, manganese, and other impurities. We append analyses of some well-marked instances from building materials used in England. (See TABLE I.)

In the subjoined table, the stones referred to may be described as follows:—

1. The *Craigleith* stone, from near Edinburgh, is a whitish grey stone with siliceous cement, slightly calcareous, with occasional plates of mica. 2. The *Darley Dale* stone, from near Bakewell, is of light ferruginous brown colour, has an argillo-siliceous cement, contains decomposed felspar with plates of mica, and has irony spots. 3. The *Heddon* stone, from near Newcastle-on-Tyne, is of light brown ochrey colour, and is similar in composition to that from Darley Dale, with the exception of the plates of

* "Western Islands of Scotland," vol. ii. p. 221.

mica. 4. The *Kenton*, from the same district, is also of light irony brown colour, and contains mica in the planes of bedding. It has an argillo-siliceous and ferruginous cement. 5. The *Mansfield* stone (Nottinghamshire) has a rosy brown colour and a magnesio-calcareous cement.*

TABLE I.

ANALYSES OF SANDSTONES.

Constituent minerals.	1. Craigleith, SG=2·232.	2. Darley Dale, SG=2·628.	3. Heddon, SG=2·229.	4. Kenton, SG=2·247.	5. Mansfield, SG=2·338.
Silica	98·30	96·40	95·10	93·10	49·40
Carbonate of lime......	1·10	0·36	0·80	2·00	26·50
Carbonate of magnesia..	0·00	0·00	0·00	0·00	16·10
Iron alumina	0 60	1·30	2·30	4·40	3 20
Water and loss	0·00	1·94	1·80	0·50	4·80
	100·00	100·00	100·00	100.00	100·00

531. The chief varieties of sandstone rocks are, 1st. *fine-grained sandstones,* more or less adapted for building purposes; 2nd. *flag-stones* or *laminated sandstones,* which are sometimes even flexible, and are chiefly used in paving, though sometimes for coarse roofing; 3rd. *grit-stones* or *fine conglomerates,* in which quartz pebbles, usually small, are associated with smaller grains, and cemented together into a hard mass, often used in the manufacture of mill-stones; and 4th. *coarse conglomerates* or *pudding-stones,* of which examples are not rare, but which are seldom available for any useful purpose. They all occur in most parts of the world, and are almost all more or less coloured by iron. They are little affected by acids, and usually stand exposure well, but they are often associated intimately with other sandstone rocks much less pure; and if these impurities consist of carbonates or sulphates of lime, or contain potash or soda, the rock is apt to lose its valuable and durable character, and is exposed to injury from disintegration.

532. Besides being used for building, the fine white sands, when pure, are valuable in the foundry, in the manufacture of glass, and in sawing marble and other stones. The fine hard kinds are used as whetstones and scythe-stones, and a peculiar quartzose conglomerate, called *itacolumite,* found in Brazil, is the matrix of the topaz and some other gems, while a similar, but peculiar, siliceous grit in India contains diamonds.

In quartzose rocks, and in the crevices in such rocks, are found many valuable metals, of which gold and platinum are the most remarkable. Iron is also widely distributed through them, and crystals of titanium often penetrate massive quartz as well as quartz crystals. Garnets often occur in quartz rock.

* Report of Committee on Building Stones.

533. Of the fragments of quartz rock and of the harder sandstones are formed many of the beds of gravel common in various parts of the world, which appear to be deposits left behind by moving water, and originally derived from the breaking up and wearing away of much larger masses. Except when a little oxide of iron or carbonate of lime has served as an imperfect cement, such gravel has rarely undergone any true consolidation; and thus we have in it an example of siliceous rock in a very irregular and confused state. Blocks of other kinds of stone not unfrequently appear in it.

534. Quartz rock, and siliceous accumulations of all kinds, are usually very barren of organic remains — a fact easily explained, when we consider their origin, since gravel and sands are not those places where marine animals chiefly inhabit, and any materials of organic origin conveyed to such places would be exposed to much injury from mechanical attrition. The soluble salts and other mineral ingredients of organic beings might, however, in many cases become collected in the vicinity of siliceous aggregations, and perhaps under various conditions tend to modify the rock. This is especially the case with seaweeds, which have in some instances been present in great abundance, and of which indications are found in the chemical composition of the enclosing rocks, and animal bitumen is also sometimes found in sand and quartz rock to a very remarkable extent.

The Lime Group.

535. A piece of soft chalk, or the soft calcareous mud produced from the rubbing and pounding of limestone by a river or the sea, presents to us the best and simplest example of calcareous rock in its first stage. It consists of nearly pure carbonate of lime, combined, however, with a small proportion of silica. When from calcareous mud a portion of the water is evaporated, a certain amount of solidification is produced, and we see before us a mineral into which water is readily absorbed, and which, if exposed to the action of heat under considerable pressure, assumes a hard and compact texture, becoming either chalk, limestone, or marble; but it is rarely that calcareous rock occurs in nature in a simple and pure state, even crystalline masses often containing foreign substances. Among them silica is perhaps the most universal, while magnesia, and to a smaller extent, potash, soda, iron, manganese, and even phosphorus and fluorine, may be mentioned as extremely common.

Limestones, moderately solidified and tolerably pure, are either finely granular, like the harder varieties of chalk, or else approximate to the condition of what we may call earthy marble, examples of which are abundant in the south of France and the north of Italy,

and are well adapted for building purposes. They are extremely compact and of close texture, and often show a conchoidal fracture when broken. They are hard, white or cream-coloured, and contain few of the fragments of animal substances present during their formation. They have undergone, apparently, the same change as the finer white sandstones, exhibiting the result of a simple exposure to the action of the laws of cohesion under favourable circumstances.

536. Few, however of the common limestones of any country are so nearly simple in their composition, and very few indeed, if any, fail to exhibit in some way or other marks of an origin which has some reference to organic beings. When we consider for a moment the vast quantity of carbonate of lime which is daily and hourly being separated to form the solid parts of animals, and remember that this operation goes on in the depths of the ocean, and on its shores, to a far greater degree than is possible on shore—that every race of molluscs, crustaceans, and zoophytes, inhabiting shells or building coral reefs, or other stony skeletons and dwelling-places, secretes a quantity of this material, which is obtained from the sea-water, and rendered permanent in a solid form:—when we remember, too, that the quantity secreted by each individual during its brief existence is almost always greater in proportion as the animal is smaller, and its life shorter, and that at the same time the number of individuals is then largest and the multiplication of the species most rapid, little astonishment will be felt at the vast accumulations thus made in the course of years, or the result thus produced upon the mass of solid matter in the earth's crust.

The composition of limestones, even of those that exhibit no organic bodies, corresponds so nearly to that of the solid matter secreted by animals, and it is so difficult to understand the deposit and formation of carbonate of lime without some such means, that most naturalists have admitted, as highly probable, the suggestion that all rocks of the kind, exhibiting mechanical structure, or affording organic remains, are partly, if not entirely, of organic origin. Whether some of those that exhibit even the greatest amount of crystalline structure, may not be of the same kind, we shall presently consider. We have not here taken into account the deposits of travertin and stalactite from fresh water, as these are never exhibited on a very large scale, and do not affect the general question.

537. Referring to an estimate in a former paragraph (§ 44), we find that the total weight of carbonate of lime in solution in salt water may be roughly estimated at about 400 millions of millions of tons. This would correspond to more than 2,000,000 of tons of carbonate of lime in each square mile of ocean, allowing a mean depth of 1000 feet, and this quantity no doubt is restored as fast as

it is removed, being dissolved by the water where the waves beat against limestone rocks in various parts of the world. It must also be amply sufficient for the supply of all the marine animals, since it is probable that only a part of the solid matter secreted becomes permanently included in rock masses, and even this part is most abundantly secreted near shore.

538. The modifications of limestone are abundantly distributed, and are many of them very valuable. The principal are, *Oolites; Compact limestones,* more or less crystalline; Limestones that may be called *Massive marbles;* and innumerable varieties of *Crystalline marble.* Other kinds are present only in comparatively small quantities and in particular districts, but these are very widely spread, and appear under different names in every district, the degree and nature of the modification varying almost indefinitely.

Oolite is the name given to limestones made up more or less completely of minute egg-shaped particles (whence the name), generally concentric, and often consisting of calcareous matter accumulated about some minute point of organic origin. Many of the common building stones of England, especially those from the neighbourhood of Bath, Portland Island, Ketton, and others, are of this kind, and analyses of a few of the more important will be found useful. Some of these are given in TABLE II.; and we may here remark that the first set, No. 1 to 6 inclusive, give the composition of the residuum, and are therefore more detailed than the others. These are copied from the "Memoirs of the Geological Survey of Great Britain," vol. ii. pt. ii. p. 685. The rest are from the "Report on Building Stones for the new Houses of Parliament," and were made under the superintendance of the late Professor Daniell.

539. Compact limestones and massive marbles are frequently so far altered from their original condition as to have acquired a distinct and semi-crystalline texture, a fine grain, and a more or less jointed or crystalline structure. They are often coloured by metallic oxides, of which those of iron are by far the most abundant; they constantly exhibit organic remains, of which corals and shells are the most common; and they almost always abound in small crevices, which may perhaps be the result of contraction owing to the removal of a portion of the water they once contained. These crevices not unfrequently contain crystals of pure carbonate of lime. Caverns are very common in limestone rocks.

Compact limestones pass by insensible degrees into true crystalline marbles, of which the finest examples are obtained from Italy and Greece, but which are not wanting in other districts. We append, as a useful note to this part of the subject, another extract from the work of Dr. Macculloch already quoted :—

540. Speaking of "primary limestone," the name sometimes given

TABLE II.

ANALYSES OF VARIOUS LIMESTONES.

Constituent minerals.	1. Downside n. Bristol, SG=2·682.	2. Dundry n. Bristol, SG=2·730.	3. Combe Down, Bath, SG=2·684.	4. Red Croft, Portland, SG=2·631.	5. Caen, Normandy, SG=2·631.	6. Tainswick, Gloucestershire, SG=2·605.	7. Ketton, Rutlandshire, SG=2·706.	8. Barnack, Northamptonshire, SG=2·706.	9. Ham Hill, Somersetshire, SG=2·695.	10. Chilmark, Wiltshire. SG=2·621.
Carbonate of lime	92·38	95·09	95·44	96·43	82·48	97·61	92·17	93·40	79·30	79·00
Carbonate of magnesia..	0·30	0·65	......	1·05	......	0·81	4·10	3·80	5·20	3·70
Carbonate of soda	......	0·62	0·71	0·57	......	0·71				
Silica	4·82	0·76	0·64	0·85	13·62	0·22	......	......	4·70	10·40
Alumina	......	0·30	0·59	0·07	......	......	0·90	1·30	8·30	2·00
Magnesia............	......	......	0·28	......	0·50					
Sulphate of lime	......	0·18								
Chloride of sodium	......	......	0·05							
Phosphoric acid	......	......	......	Trace						
Sulphuric acid	......	......	Trace							
Protoxide of iron......	......	0·79	1·13	......	0·73	0·39				
Peroxide of iron	0·24	......	......	0·30						
Oxide of manganese....	......									
Carbonate of iron......	0·32									
Carbonate of manganese	0·66									
Chlorine	......	......	0·03	......	......	Trace				
Water	0·48	0·83	0·81	0·64	1·62	0·75	2·83	1·50	2·50	4·20
	99·20	99·22	99·68	99·91	98·95	100·49	100·00	100·00	100·00	99·30

The specific gravities are those of particles, and therefore higher than those of the solid stone. In dry Bath stone the difference is ·836, and in Portland ·557. The stones are all so common and well known, that it is not necessary to describe them in further detail. Under the head "water" in the last four analyses (7—10) are included various substances not accurately determined.

to the variety we are now considering, he says, "It exists, either in a considerable succession of unmixed beds, or else in rare and slender strata, or laminæ intermixed in small proportion with some other rock; most frequently, with the argillaceous schists. It is also found in irregular masses or large nodules, which can scarcely be said to possess a stratified shape, and which very much resemble, as already remarked, the masses of serpentine that occur in similar situations. Excepting in the crystalline form it is never found in veins, and in this respect it is exactly analogous to quartz, the veins of which are very similar and generally found in the same situations.

"Beds of limestone are often bent, and even considerably contorted, as are those of the rocks which it accompanies; and these flexures are most visible in the varieties which contain mica. They seem to present no variations of structure but the laminar, which are deserving of notice.

"The texture varies from the highly crystalline, of a larger or finer grain, to the uniformly compact, and the earthy; and the mineral composition requires no notice, as it is fundamentally a simple rock. It is, however, much modified in aspect by the presence of unessential minerals."*

541. We conclude this description of lime rocks with an account of some of the more remarkable varieties of marble, chiefly from Dana's "Manual of Mineralogy." It necessarily includes some combinations that we shall afterwards again mention, and also some referred to in a previous paragraph as minerals :—

"*Verd antique marble*—*Verde antico*—is a clouded green marble, consisting of a mixture of serpentine and limestone. A marble of this kind occurs at Genoa and in Tuscany, and is much valued for its beauty. A variety is called *Polzivera di Genoa*, and *Vert d'Egypte*.

"The *Cipolin* marbles of Italy are white, or nearly so, with shadings or zones of green talc. The *Cardiglio* is a grey variety from Corsica.

"*Compact limestone* usually breaks easily into thick slabs, and is a convenient and durable stone for building and all kinds of stone work. It is not possessed of much beauty in the rough state. When polished it constitutes a variety of marbles according to the colour; the shades are very numerous, from white, cream and yellow shades, through grey, dove-coloured, slate-blue or brown, to black.

"The *Nero-antico* marble of the Italians is an ancient, deep black, marble; the *Paragone* is a modern one, of a fine black colour, from Bergamo; and *Panno di morte* is another black marble with a few white fossil shells.

"The *Rosso-antico* is deep blood-red, sprinkled with minute white dots. The *Giallo antico*, or yellow antique marble, is deep yellow with black or yellow rings. A beautiful marble from Sienna, *Brocatello di Siena*, has a yellow colour with large irregular spots and veins of bluish-red or purplish. The *Mandelato* of the Italians is a light red marble, with yellowish-white spots; it is found at Luggezzand. At Verona, there is a red marble, inclining to yellow, and another with large white spots in a reddish and greenish paste. The *Bristol marble* is a black marble, containing a few white shells, and the *Kilkenny* is another similar kind.

"The *Portor* is a Genoese marble, very highly esteemed. It is deep black, with elegant veinings of yellow. The most beautiful comes from Porto-Venese, and under

* Macculloch's "Classification of Rocks," p. 365.

Louis XIV. a great deal of it was worked up for the decoration of Versailles. *Ruin-marble* is a yellowish marble, with brownish shadings or lines, arranged so as to represent castles, towers, or cities in ruins. These markings proceed from infiltrated iron or manganese. It is an indurated calcareous marl.

" *Oolitic marble* has usually a greyish tint, and is speckled with rounded dots, looking much like the roe of a fish. *Shell marble* contains scattered fossils, and may be of different colours. *Crinoidal*, or *encrinital marble* differs only in the fossils being mostly remains of encrinites, resembling thin disks. *Madreporic marble* consists largely of corals and the surface resembles delicate stars: it is the *Pietra stellaria* of the Italians. *Fire marble*, or *Lumachelle*, is a dark brown shell-marble having brilliant chatoyant reflections from within. *Breccia marbles* and *Pudding-stone marbles* are polished calcareous breccia, or pudding stone.

" *Stalagmites* and *Stalactites* are frequently polished, and the variety having banded shades is often highly beautiful. The *Gibraltar stone*, so well-known, is of this kind. It comes from a cavern in the Gibraltar rock, where it was deposited from dripping water. It is made into inkstands, letter-holders, and various small articles.

" Wood is often petrified by carbonate of lime, and occasionally whole trunks are changed to stone. The specimens show well the grain of the wood, and some are quite handsome when polished.

" The finest statuary marbles come from the Italian quarry at Carrara (*Carrara marble*); from the Island of Paros, whence the name *Parian;* from Athens; and from Ornofrio, in Corsica, of a quality equal to that of Carrara. The Medicean Venus, and most of the fine Grecian statues are made of Parian marble. These quarries, and also those of the Islands of Scio, Samos, and Lesbos, afforded marble for the ancient temples of Greece and Rome. The Parthenon, at Athens, was constructed of marble from Pentelicus."

542. The common minerals found in veins in limestone rocks are Calc spar; Fluor spar; the sulphurets and other ores of lead and zinc, the former generally associated with silver; the sulphurets, chromate, and other salts of iron; the oxides of titanium; several hornblendic and augitic minerals; Mica and Chlorite; Salts of barytes and strontian; Serpentine, Talc, Steatite, Apatite, Garnet, Emerald, Graphite, and Bitumen. Very perfect crystals of quartz sometimes occur.

543. Sulphate of lime, or Gypsum, is frequently present in sufficient abundance to be designated as rock, and is then valuable either as yielding Plaster of Paris or furnishing Alabaster for ornamental purposes. In the former case it is earthy or massive, but in the latter semi-crystalline. It is also found crystalline, as in Selenite. Gypsum is frequently associated with sands accompanying beds of common Rock-salt (chloride of sodium). The masses thus found are often very thick, but limited in extent.

The gypsum beds of the neighbourhood of Paris consist of three distinct masses separated by beds of marl (calcareous clay), and having numerous thin bands of clay and marl interstratified with each. Each mass has some special characteristic, and may be traced to a considerable distance. They contain organic remains rather abundantly distributed. Gypsum occurs frequently in lenticular or wedge-shaped masses.

Phosphate of lime occurs as a rock in some districts, though hardly

to a sufficient extent to be worth referring to here. It is usually massive, but sometimes earthy and sometimes crystalline.

Fluate of lime, or fluor spar, called sometimes *Blue John* by the miners of Derbyshire, is occasionally found in large quantities as a massive mineral.

544. Carbonate of lime, as we have seen, often contains a small proportion of carbonate of magnesia; but when the latter constituent is present in larger quantity, the mineral is called *Dolomite.* Very large rock masses of dolomite occur in England and elsewhere. Dolomite has lately been recommended as a building material, and is used in the construction of the new houses of Parliament. The following analyses of five of the principal magnesian limestones employed for building purposes, will be useful for comparison with other rocks :—

TABLE III.

ANALYSES OF MAGNESIAN LIMESTONES.

Constituent minerals.	1. Roach Abbey, SG=2·134.	2. Park Nook, SG=2·138.	3. Huddlestone, SG=2·147.	4. Bolsover Moor, SG=2·316.	5. Bolsover Quarry, SG=2·324.
Carbonate of lime......	57·50	55·70	54·19	51·10	54·05
Carbonate of magnesia..	39·40	41·60	41·37	40·20	38·58
Silica	0·80	0·00	2·53	3·60	1·30
Iron oxide	0·70	0·40	0·30	1·80	1·36
Manganese oxide......	......	......	......	Trace	1·50
Water and loss	1·60	2·30	1·61	3·30	2·71
	100·00	100 00	100·00	100·00	100·00

1. The *Roach Abbey* stone, from near Bawtry, in Yorkshire, has a whitish cream-colour; semi-crystalline; with dendritic spots of iron or manganese. 2. The *Park Nook*, from near Doncaster, is cream-coloured, and in part crystalline. 3. The *Huddlestone*, from near Sherburne, in Yorkshire, is also a whitish cream-coloured stone, and semi-crystalline. 4. The *Bolsover* stone, from near Chesterfield, in Derbyshire, is of light yellowish brown colour, and almost crystalline in its texture. The other Bolsover stone (5) is from near Mansfield, and is of brownish colour. The specific gravities in this table are those of dry masses. Those of the crushed particles are much higher, ranging between 2·840 and 2·867. The limestone used for the Houses of Parliament is from the neighbourhood of the Bolsover quarries.

The Clay Group.

545. Under this title are included chiefly impure silicates of alumina; and the most remarkable varieties of these have been already described amongst minerals (§401-403). Common clay usually contains, besides silicate of alumina, a variable proportion of silica, iron, lime, and water, with traces of manganese, potash, soda, magnesia, and carbon, and being more frequently and more abundantly mixed with such impurities than either limestones or sandstones, some extent of

TABLE IV.

ANALYSES OF VARIOUS IMPORTANT CLAYS.

Component minerals.	1. Stour-bridge clay.	2. Fire clay, Sheffield.	3. Pipe-clay, Devon-shire. (Berthier.)	4. Potter's-clay, France. (Berthier.)	5. Kaolin, Dartmoor. (Fownes.)	6. Porcelain clay, Vanvres.	7. Fuller's-earth, Reigate. (Bergman.)	8. Shale, Saxony. (Lampa-dius.)	9. Shale, Edin-burgh. (Walker.)	10. Clay-slate, (D'Aubuis-son.)
Silica	63·70	58·40	50·61	49·20	47·20	51·84	50·80	50·20	58·22	48·00
Alumina	22·70	22·50	38·19	24·60	38·80	26·10	23·00	21·00	17·50	25·50
Lime	......	......	......	1·97	0·24	2·25	2·30	......	Trace	
Magnesia	......	......	......	....	......	0·23	0·20	......	......	1·60
Potash	......	......	......	....	1·76	......	......	......	......	4·70
Soda	......	......	......	....		......	......	......	2·02	
Iron oxide	2·00	3·00	......	6·23	Trace	4·91	0·70	0·90	10·53	11·30
Manganese oxide	......	......	......	....		....	0·20	......	4·62	0·50
Carbon	......	5·80	......	....	......	......	......	18·11	......	0·30
Water	10·30	10·30	11·20	18·00	12·00	14·58	24·50	8·22	6·70	7·60
	98·70	100·00	100·00	100·00	100·00	99·91	101·70	98·43	99·59	99·50

The above table has been carefully compiled to give an idea of the composition of some of the most important varieties of clay. The first is the well-known material used in the manufacture of the best fire-brick, and requires no further remark. The next (No. 2) is a material for crucibles used in the manufacture of cast steel. Nos. 3, 4, explain themselves. No. 5 is one of more valuable porcelain clays of Devonshire. No. 6 is another porcelain clay used at Sévres, and mentioned by Brongniart. No. 7 is the material formerly much employed for fulling cloth, and still valuable for that purpose.

The remaining three are rocks not directly employed except mechanically. The shales differ chiefly in the relative proportions of carbon and iron, and the clay-slate may be regarded as a fair average specimen. Where the authority for the analyses is not given, they are quoted from Dufrénoy (Minéralogie).

change, or modification, can generally be discovered even in the most mechanical and least altered deposits. Thus in common clays we find bands of fuller's earth, crevices filled with iron pyrites, sulphate of lime (gypsum), or the salts of barytes, and other minerals which seem to mark a separation of materials, at one time distributed through the mass, but now collected into distinct spots.

546. Clays exhibit, on the whole, more mixed composition than other rocks; and thus, from their chemical composition, independently of other causes, are liable to undergo alterations. The presence of sulphuric acid (obtained from the decomposition of pyrites), and of many alkaline earths and other substances, must often originate changes, and also greatly aid those commenced during the process of desiccation, and when electric currents are passing through the mass. It is not easy to select from the number of such modifications those which first demand attention, but the concentric structure, lamination, and separation of distinct minerals into veins or crevices, afford several that are highly interesting, and most valuable for study.

547. Many masses of clay found at and near the earth's surface, though of great thickness, exhibit but little division into distinct bands; while others again split readily in one direction into plates more or less thin, hard, and durable, according to the place from which they are taken. Clays presenting this condition are called *shales*, and they are usually, if not always, coloured by iron and mingled with silica, limestone, and other impurities. The clays associated with coal are usually of this kind. Clays that are not thus modified as well as most shaly or schistose rocks, are broken by numerous fissures, which seem to be chiefly the result of contraction; and we have already mentioned that these fissures are often filled with minerals, separated by a chemical process from amongst the impurities or miscellaneous contents of the mass. When such fissures occur at tolerably regular intervals, and at right angles to each other, they tend to divide the whole into rhombohedral or prismatic masses, and thus approximate to a crystalline structure; and, frequently, when no such structure prevails, the separation of particular minerals takes place in nodules, which are not usually concentric but laminated.

From shale to schist, and from schist to slate, are transitions often so gradual as to be hardly traceable. All three rocks are laminated; but the latter frequently has its planes of lamination lost and obliterated by the cleavage which has supervened, and which has often induced a condition nearly crystalline. We propose, however, to describe these schists and slates in some detail, as they form important rocks, and must be distinguished from each other, and from shales and clays.

548. Schists are fundamentally silicates of alumina; but varieties often present so large an admixture of sand, mica, chlorite, talc, horn-

blende, actinolite, and other minerals, as to admit of separate description. The presence of these is also usually connected with atomic change or metamorphosis, exhibited in fact in this frequent interpolation of simple minerals; and thus the circumstances under which the latter occur become important as part of the history of the rock. The following account of argillaceous schist or clay-slate, one of the most abundant and interesting of the whole group, will be read with interest. It is from the work of Dr. Macculloch, already quoted; and its length is fully justified by the importance of the subject.

549. "The stratification of argillaceous schist admits of no question, however difficult it may often be to trace the beds. These are sometimes extremely irregular in their forms and disposition, and they vary very much in dimension. Where they alternate with other rocks they are often very thin; but where they occur in extensive tracts and unmixed, they attain to such a thickness that it is frequently impossible to discover the places where they are separated. In this respect they present the same difficulty as micaceous schist, in which it is often impossible to trace the divisions of the strata. These separations between the beds are sometimes caused by intervening rocks of some other character; but more frequently they result from a change of texture in the approximate parts of the general mass. The strata of argillaceous schist are subject to flexures similar to those in micaceous schist and gneiss; but the rock itself is rarely contorted in the very minute manner in which those sometimes are.

"It presents, also, some varieties of internal structure, one of which constitutes its chief value for the purpose of architecture. This is the schistose disposition, in consequence of which it is capable of being split into slates of considerable tenuity in many cases, while, in others, it rather presents imperfect indications of a fissile tendency than the property of dividing into continuous plates. This quality occurs both in the finer and coarser varieties; but the former possess it in the most perfect manner, although many of the latter, sometimes called *grauwacke schists*, are sufficiently divisible for economical purposes.

"In most cases, these laminæ are indefinitely, although imperfectly, divisible, so that the entire structure of the stone is schistose, or nearly scaly; but, in others, it appears limited to some definite dimension, so as to afford examples of that which is distinguished from the schistose structure by the term *laminar*.

550. "In general the schists are flat, being sometimes also smooth, but in other cases they are minutely undulated. In some rare instances, however, the laminæ are bent while the strata themselves are straight. This occurrence indicates that the laminar disposition is not invariably the consequence of the mode in which the rock was deposited; a fact which is further proved by the following circumstances:—

"Although the fissile tendency is often parallel to the plane of stratification, it will sometimes be observed to lie in an oblique direction to that; proving, as in the former case, that it is the result of a concretionary structure. A more certain proof of this is in some instances afforded by the persistence of the fissile tendency, or the lines of splitting, through beds which in different places present an alternating fine and coarse texture indicating the true position of the stratum, or that in which the deposition of the materials took place.

"As the seams, or divisions, of the strata of argillaceous schist are often invisible, either in consequence of their great distance from each other, or from the nature of the ground, or from other causes, the fissile direction may often be mistaken for the plane of the stratification. The alternation of the fine and coarse kinds here serves to mark the true disposition of the bed, even where the different textures are not actually divided; but where neither of these indications are present, there seems to be no criterion by which the one can be distinguished from the other.

"This doubt is necessarily confirmed by the fact that, in many instances, the fissile tendency is actually parallel to the plane of stratification, as it invariably appears to be in the secondary argillaceous schists or slates. In these cases it must ever remain a doubt whether this structure is the result of a concretionary arrangement or a mechanical deposit. From the other instances occurring in the same class of rock, we should be inclined to determine on the former; while from the analogy of the shales, of which the mechanical structure is proved by the vegetable remains deposited in them, we should decide on the latter.

"A fibrous structure is not unfrequent in the finer varieties of argillaceous schist, and it is often combined with the laminar or schistose disposition. It may lastly be remarked on this subject of structure, that, in a bed which is principally laminar, there are sometimes found nodules of the same substance massive and imbedded; the laminæ in the vicinity accommodating themselves to the form of the nodule.

551. "Beds of argillaceous schist are frequently divided by natural joints, which are either at right angles, or oblique, to the plane of stratification. According to these circumstances, they frequently separate into rhomboidal or prismatic fragments, more or less regular, and presenting great diversity of form. They are, moreover, very frequently intersected by numerous and minute veins of quartz or of calcareous spar, which, in the case of contortions, frequently follow the flexures of the schist in which they lie—a fact of considerable interest in a geological view.

552. "The essential minerals of the argillaceous schists are the peculiar indurated clay which by itself forms all the simple varieties, together with quartz and mica, which enter into the coarser or

compound kinds. The conglomerated varieties, or the coarse grauwackes, contain, in addition to these, fragments of some of the primary rocks. It ought also to be added, that, in some rare instances, grains of felspar occur in such a manner as to give the rock a porphyritic appearance.

"According to these different circumstances, the texture of the several varieties differ; the finer presenting one which is perfectly compact and uniform, while the micaceous, the sandy, the gravelly, and the conglomerate kinds, are each characterized by textures which these terms will sufficiently explain. A parallel disposition of the mica, is sometimes, in the micaceous varieties, a common cause of fissility, where no such tendency is perceptible in the base. In many of these rocks, it is apparent that the parts are united by something more than a mechanical adhesion. This seems to be the case in many of the compact kinds, or the hone slates, and occasionally in some of those which contain abundant grains of quartz; but, in the greater number, the indurated clay forms the cement which unites all the fragments whether great or small into a solid mass.

"The last circumstance of importance in the general character of the argillaceous schists is, that they sometimes contain organic remains, and even in considerable abundance." *

553. It might naturally be expected that the minerals associated with argillaceous schists would be numerous and varied. They include oxides and sulphurets of iron and copper, strings of quartz, Opal, Calc spar, Wavellite, Cyanite, Andalusite, Staurotide, Garnet, Epidote, Lazulite, Topaz, Stilbite, Chlorite, and others. In some schists the pyrites are so abundant and so readily decomposable, that they form aluminous efflorescences on exposure, and convert the schist into alum-slate. The same thing happens occasionally with shales.

The finer kinds of roofing slate present the most altered form of this rock, and exhibit perfect cleavage, completely obliterating all marks of organic remains and original bedding, and also a perfect system of joints dividing the mass into rhombohedral portions. In this way, the approach towards crystallization is not less perfect, though in a different way, than that of sand in quartz rock, and limestone in crystalline marble.

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554. We pass on now to combinations of the minerals forming simple rocks; and although this subject has been partly forestalled in previous paragraphs, there yet remain many points of interest to be alluded to. These include first, a notice of some ordinary mechanical admixtures of sand, lime, and clay, that do not properly come under the denomination of any one of these titles; Secondly, an account

* Macculloch's "Classification of Rocks," p. 347 et seq.

of the modification of simple rocks by the association of a large proportion of simple minerals; Thirdly, an account of certain species and groups of simple minerals, forming rocks of great extent, too complicated to be included amongst any rocks hitherto described; And lastly, a notice of what are called porphyritic rocks, or those very commonly described as granites, and others nearly allied to them. All these form an imperfect series, commencing with the strictly mechanical masses, and terminating with others as distinctly crystalline.

555. Admixtures of sand, lime, and clay, forming rocks, are rarely sufficiently uniform to admit of definition. They form marls and loams, calcareous clays and argillaceous limestones, and are met with in various parts of the world, having values very different according to the circumstances under which they occur. They often owe part of their calcareous contents to the organic bodies embedded in them, and can hardly be expected in any case to retain the same character over a wide area. We must leave any detailed consideration of them to future chapters, when referring to them as geological phenomena,

TABLE V.

ANALYSES OF COLOURED MARLS.

Component minerals.	No. 1.	No. 2.	No 3.	No. 4.
Silica	48·80	48·40	70·20	66·50
Alumina	9·02	8·89	19·20	22·90
Lime	8·24	8·70	0·22	0·17
Magnesia	0·99	0·93	....	....
Soda	0·49	0·48	0·10*a*	....
Potash	3·53	3·25	....	....
Iron protoxide	12·83	4·62	....	1·70
Iron peroxide	....	9·08	6·00	3·20
Carbonic acid	10·13	8·64	0·18	0·13
Phosphoric acid	trace	trace	....	....
Sulphuric acid	0·16	0·26	....	trace
Chlorine	trace	trace	....	....
Organic matter	1·86	1·15	....	1·30*b*
Water and loss	3·95	4·59	4·10	4·10
	100·00	98.99	100·00	100·00

a. Chloride of sodium. *b.* Carbonaceous matter.

merely appending here a few analyses of marls; No. 1 being a blue and No. 2 a red variety from Aust Cliff in Somersetshire, opposite Chepstow at the mouth of the Severn, and No. 3 a red and No. 4 a grey variety from near Milford Haven, on the opposite coast of the Bristol Channel. The two first are from the New red and the latter from the Old red sandstone.*

* "Memoirs of the Geological Survey of Great Britain," vol. i. pp. 55 and 254.

556. The various schists already mentioned (see § 548), next demand careful notice. *Mica schist* is a laminated rock of variable texture and fracture, and grey colour, consisting essentially of quartz and mica in varying proportions, and often with many accidental ingredients. Garnets are very common in rocks of this kind, and they sometimes abound to such a degree as almost to equal in quantity the including rock and modify its character. Tourmaline, Beryl, and Corundum are also found in it. *Chlorite schist* consists of quartz and foliated chlorite, and may be recognised by its greenish tint, and also by the more tender and flexible character of the chlorite and its soapy feel. *Talcose schist* is the name given to those rocks where talc replaces the mica in association with quartz. Diallage, Asbestos, and other magnesian minerals occur in it.

557. Following out the plan already adopted in other cases, we here append analyses of several schistose rocks, and others which may be regarded as of the same kind (see TABLE VI). They are estimated from the contents of the component minerals, supposed to be mingled in the usual proportion, and are thus mean results. They are chiefly taken from De la Beche's "Manual," 3rd ed., p. 440.

TABLE VI.

COMPOSITION OF VARIOUS METAMORPHIC ROCKS.

Component minerals.	Gneiss. (Quartz, felspar, and mica).	Gneiss (Quartz, albite, and mica).	Mica-slate (Quartz and mica)	Mica-slate (Quartz, mica, and garnet).	Chlorite-slate (Chlorite and Quartz).	Talcose-slate (Talc and Quartz).	Hornblende-rock (Hornblende and felspar).
Silica	70·06	71·86	73·07	61·94	63·71	78·45	54·86
Alumina	15·03	15·20	13·08	15·45	8·95	0·40	15·56
Lime	0·37	0·25	0·17	0·45	0 25	2·00	7·29
Magnesia	1·66	1·70	2·49	1·66	7·28	13·20	9·39
Potash	7·92	3·37	5·06	3·37	0·78	0·00	6·83
Soda	0·00	3 31	0·00	0 00	0 00	0·00	0 00
Iron oxide	2·97 }	3·01	{ 4·08	14·72	15·31	4·05	4·03
Manganese oxide	0·20 }		{ 0·30	1·23	0·00	0 00	0·11
Fluoric acid	0·36	0·36	0.54	0·36	0·00	0·00	0·75
Water	0·66	0·35	1·00	0·66	3·46	1·50	0·00
	99·23	99·41	99·79	99·84	99·74	99·60	98·82

558. *Hornblende rock*, *Greenstone* and *Hornblende schist*, are varieties of a rock frequently associated with the preceding schists, into which also they pass. Hornblende rock is usually, but by no means always, schistose. It consists of varieties of hornblende, which are of dark green or black colour, and either with or without felspar. It contains no quartz though a large proportion of silica. The colour

of the rock, being derived from the combinations of black and green so characteristic of hornblende as a mineral, with the white or flesh-colour of the felspar, produces a variety of tints, in which grey often preponderates, though not without a prevailing tint of green. In some cases the hornblende is replaced by actinolite.

559. The composition of hornblendes has been already given in the tables of analysis of simple minerals in a former chapter; but we must now recur to the subject to connect it with that of the rocks called *Trap* and *Basalt*, and with *Trachyte*, the necessary result, as it is generally assumed, of volcanic agency. All the rocks hitherto mentioned have been more or less laminated in planes of bedding, however obscure, and this is the case also with such rocks as *Hypersthene*, *Diallage*, *Serpentine*, and some others, which are so nearly crystalline as to be frequently included amongst simple minerals. No marked line can indeed be safely drawn between these and the Hornblendic and Augitic groups of minerals, for all have very close relations with each other, but still a good deal of difference in the rock masses may be traced, not only or chiefly in mineral composition, but in the localities in which each prevails, and the circumstances of association. We annex (TABLE VII.) a series of analyses of such of these minerals as exhibit the nearest analogies, whether of composition or association. The analyses are chiefly those quoted in Nicol's "Mineralogy," but several are added from other authorities.

560. But we may go one step further, and consider here another class of rocks, of which the materials are various simple minerals cemented together, or various minerals crystallized in a base, these also being modifications of ordinary conditions. Certain conditions of temperature may be required in this further transformation; but it has not been proved that intense heat, or at any rate a state of igneous fluidity, are at all essential. Rocks of this kind are called *Porphyry* or *porphyritic*, and the best known (a combination of quartz, felspar, and mica) is universally recognised as *Granite*. But there is a rock called *Gneiss*, apparently mechanical in its structure, which forms a sort of intermediate state, and which should be first considered as exhibiting the transition from the schists already mentioned (consisting of mica, chlorite or talc, with quartz), to the more regular admixture of crystals of felspar, mica, and other minerals in a crystalline base generally consisting of quartz.

561. Gneiss is essentially a compound of quartz, felspar, and mica or hornblende, all more or less crystalline, but presented in a mechanical order of arrangement, the crystals preserving a general and rough parallelism, so as to give a foliated appearance to the rock, and cause it to split rather more readily in some one direction than in any other. The dimensions of the strata are extremely various, being often thick when not alternating with other schistose rocks,

TABLE VII.

ANALYSES OF VARIOUS SIMPLE MINERALS FORMING ROCKS.

Component minerals.	1. Tremolite, St. Gothards.	2. Actinolite, Taberg.	3. Hornblende (common), Lindbo.	4. Hypersthene, Paul's Island.	5. Diallage, Ural.	6. Serpentine, Ural.	7. Basalt, Beaulieu.	8. Basalt, Saxony.	9. Clinkstone. Mean of several analyses.	10. Obsidian, Pasco.	11. Pumice, Lipari.
Silica	58·07	59·75	45·06	46·11	52·60	40·80	59·50	44·50	57·66	69·46	70·00
Alumina	......	......	13·51	4·07	3·27	3·02	11·50	16·75	19·96	2·60	16·00
Lime	12·99	14·25	13·36	5·38	20·44	0·42	1·30	9·50	1·01	7·54	2·50
Magnesia	24·46	21·10	16·74	25·87	16·43	40·50	......	2·25	1·53	2·60	
Potash	......	......	......	......	......	......	1·60	......	6·06	7·12	6·50
Soda	......	......	......	......	......	......	5·40	2·60	6·98	5·08	
Iron protoxide	1·82	3·95	7·92	12·70	5·35	2·20	19·70*c*	20·00	3·42	2·60*a*	0·50*a*
Manganese protoxide	......	0·31	1·67	5·29	......	0·20	......	0·12	0·75		
Fluoric acid	......	0·76									
Water	......	......	0·22	0·48	1·59	12·02	......	2·00	2·33	3·00*b*	3·00
	97·34	100·12	98·48	99·90	99·68	99·16	99·50	97·72	99·70	100·00	98·50

a. Peroxide. *b.* Volatile matter. *c.* + 0·5 peroxide.

The student may judge from these analyses of the small amount of essential difference that exists between the component parts of many minerals and rocks, which, however, present aspects totally distinct. He will also see that a small extent of chemical action would be sufficient to convert them from one form to another. The degree of force exerted in segregating the carbonate of lime, the sulphate of barytes, or the sulphuret of iron into veins from clay rocks, or in inducing the process of lamination in them, might under other circumstances convert lava into basalt, or basalt into hornblende; and although in the latter case the presence of magnesia may seem to offer a difficulty, this is not greater than has to be explained, when we see carbonate of lime passing gradually into dolomite, a conversion known to have been carried on in various degrees without obliterating the remains of organic beings buried in the original calcareous mud.

but thin when they do so alternate. Gneiss is often hardly to be distinguished from granite even by the most experienced eye, and it is constantly penetrated by granitic veins parallel to the apparent planes of lamination. The contortions of the strata are remarkable and on a very magnificent scale.

562. "The varieties comprehended under the term gneiss are so considerable, that no general description can be given, and it is necessary to describe separately that of each variety. The three marked varieties of structure may be comprised under the granitic, the schistose, and the laminar.

"The granitic variety is distinguishable by its general resemblance to granite, which it also emulates in the infinite variety, intermixture, magnitude, and proportions of the several ingredients. It frequently passes into granite by an undefinable transition; and, both this transition and the resemblance to the granitic character, occur chiefly in those cases where the beds of gneiss are in the vicinity of granite. At the point of junction, the two rocks are sometimes undistinguishable: and a similar gradation often exists in those parts which are traversed by granite veins. The distinction consists in the general parallelism of the mica, or of the hornblende; or else of some other ingredients; from which cause the rock is either actually fissile, or else displays indications of a foliated structure. As that structure becomes more perfect, it recedes further from granite.

"In the schistose variety, the texture is commonly minute, while the position of the several minerals above-mentioned is more accurately parallel. Hence, the rock is almost always very readily fissile; and in some instances, indeed, possesses this quality in such perfection as to be applicable to the same purposes as argillaceous schist. This variety passes into quartz rock, by the loss of its mica or hornblende, or, sometimes, of its felspar also; and, in this case, its structure is commonly more granular than when it passes into micaceous schist. When it graduates into the latter rock, by the loss of its felspar, it is generally very distinctly laminar or schistose.

"The two preceding varieties are the most abundant. The laminar is rare, but it occurs in several parts of Scotland. In this variety, each constituent mineral is disposed separately in laminæ nearly continuous; and, as the quartz and the felspar are the predominant substances, it is marked by considerable peculiarity of aspect; particularly when, as is not unfrequent, the former is white, and the latter red, or when their colours are in any other manner strongly contrasted. When perfect, the laminar variety presents no trace of a granular structure; but it passes into both of the preceding, and thus loses its definite character. Although so decidedly laminar in composition, it is far less fissile than the preceding variety."*

563. The colours of gneiss vary considerably and are frequently disposed in stripes producing a much greater difference of aspect in hand specimens than is really important in the rock.

The following minerals are common in gneiss, viz.,—Actinolite, Calc spar, Epidote, Felspar, Fluor spar, Garnet, Hornblende, Idocrase, Molybdena, Oxide of iron, Quartz, Tourmaline, Zircon.

564. The composition of gneiss is that of granite, and we are now brought to the consideration of this rock by a series of transitions perfectly natural, and none of them involving any extreme amount of change. At the same time it should be clearly understood that the condition of this and many others regarded as igneous rocks does not in any case resemble that of fused rocks, since the only examples of fused rocks of which we have any distinct knowledge, present appearances totally distinct, and exhibit the simple

* Macculloch's "Classification of Rocks," p. 253.

minerals and elements of which they are compounded in an entirely distinct system of arrangement. We have no evidence that lava by any change connected with the continuance of heat could part with a large part of its soda and potash bases and obtain magnesia; still less can we show any thing like experimental proof of the original formation of felspar crystals, or mica crystals, in a siliceous base in modern or ancient lava, or pumice, or the separation of the quartz into the compact mass found in the true porphyritic rocks. These are all subsequent and true metamorphic results, and must be treated as such.

565. We append as before, in a tabular form, a series of analyses which will assist in the comprehension of this part of the subject.

TABLE VIII.

COMPOSITION OF VARIOUS PORPHYRITIC ROCKS.

Component minerals.	1. Granite (Normal).	2. Granite (Felspathic).	3. Granite (Micaceous).	4. Syenite (mean of several).	5. Greenstone (mean of several).	6. Protogine (mean of several).
Silica	72·30	74·00	68·10	69·91	54·86	75·24
Alumina	15·30	14·10	18·30	10·37	15·56	6·59
Lime	3·30*a*	2·50*a*	5·30*a*	4·86	7·29	0·33
Magnesia				6·26	9·39	9·26
Potash	7·40	6·80	6·40	4·55	6·83	4·55
Soda						
Iron oxide	......	......	......	2·69	4·03	1·08
Manganese perox.	......	......	......	0·07	0·11	
Fluoric acid	......	......	......	0·50	0·75	
Water	......	......	......	......	......	2·00
	98·30	97·40	98·10	99·21	98·82	99·05

a Includes also oxide of iron.

566. The composition of granite will be seen to conform with that of the other rocks above-mentioned much more distinctly when we consider the extremely variable composition of the component minerals, at least within certain limits. Regarding the various groups as silicates of alumina and potash, or soda, with various alkaline earths replacing the alumina or alkaline bases, there will appear little to distinguish the granites from argillaceous slates beyond their crystalline condition, and the presence of the alkaline bases in a somewhat larger proportion. It seems clear that these differences are better accounted for by supposing slow change in rocks originally mechanical by the simple action of chemical force, than by assuming —for which there is no sufficient reason—the original igneous fluidity of rocks of which many could not be elaborated in their present form

from a state of igneous fluidity by the agency of any laws not known to affect matter at the earth's surface.

567. The granites form, however, too important a group of rocks to be passed over without a more lengthened definition and description than has yet been given. It is usual to apply the name granite only to porphyritic combinations of quartz, felspar, and mica, and to recognise by other names the examples in which any substitution is made for either mineral. Thus, when hornblende replaces the mica, the rock is called *Syenite* (from the granite of Syene in Egypt); when the mica is replaced by talc or steatite, it is *Protogine* (the granite of Mont Blanc); and other names have been given to different varieties. We quote once more from Dr. Macculloch a brief but clear statement of the essential characteristics of those rocks of which granite is the type.

"Granite masses are sometimes continuous for a great space; so that they possess no definite form; or, if any such form be present, it cannot be discovered. At other times they are disposed in large definite bodies, not unaptly compared to feather-beds, separated by fissures or joints. When these masses possess large dimensions in two directions only, they often resemble the beds of stratified rocks, and have sometimes been mistaken for true strata. Occasionally these dimensions are so proportioned, that they resemble irregular spheroids; but these forms appear to have resulted from the wearing of the angles of masses originally prismatic.

"The extended beds above mentioned are frequently subdivided by fissures into smaller prismatic and cuboidal masses; and as the subdivisions generally take place in two opposite directions, or are vertical and parallel to the great mass or bed, these prisms are found piled on each other in a manner resembling huge masonry. The angles of the prisms being further subject to wear, as are the contiguous surfaces in a less degree, the result is an aggregate of irregular spheroids often piled on each other in a very fantastical manner. This consequence, it is evident, can only take place when the fissures are nearly horizontal and vertical. In all others the detached parts must fall away. A few rare instances occur in nature, where the dimensions of the prisms are so considerable in one direction, that, when grouped in erect positions, they present an irregular columnar appearance.

"Lastly, the great laminæ, or beds of granite, are often vertical as well as horizontal or inclined; and the rock thus presents continuous smooth precipices laterally, while above, it terminates in sharp peaks.

"A minute but irregular prismatic structure, independent of the former, is sometimes to be seen in granite. It is, also, occasionly minutely laminar, or exfoliates in crusts. These crusts are sometimes. concentric respecting one or more centres, at others they are flat

In some cases they appear to be the consequence of an original concretionary structure in the rock; in others it is equally certain that they are produced by the action of the atmosphere, as they occur equally in masses of artificial forms; in the shafts of columns for example, and in blocks squared by the tool.

568. "With these comprehensive geological features, are united the following mineralogical characters.

"The texture is, with one exception, always crystalline and confused; the several minerals of which it is composed interfering with each other's forms. With the single exception of the graphic variety, it is also granular; but varying much in the fineness of the texture, or in the magnitude of the parts.

"The magnitude of the parts in granite is extremely various, each constituent mineral sometimes exceeding an inch in dimensions, and at others being almost invisibly minute. Various textures are also often united in a very limited space, or the rock passes imperceptibly from fine to coarse-grained. Occasionally, also, irregular patches or veins of a fine texture, are seen imbedded in a coarser variety. In one rare instance the parts affect a spheroidal arrangement.

"Granite, therefore, consists fundamentally of quartz, felspar, mica, and hornblende, variously combined; but other minerals occasionally enter into the composition, so as to form integral parts of a common mixture. They are, it is true, comparatively rare, but they cannot conveniently be excluded from the definition.

"These minerals are, Actinolite, Chlorite, Talc, Compact felspar, and Steatite.

569. "The colours of granite are infinitely varied; that of the hornblende, where it exists, being invariably black, or an extremely dark green: it only contributes to modify that of the rock, by the proportion which it may bear to the other ingredients. When in great excess, it forms compounds nearly black: in other cases it produces various tints of grey. Grey and black tints also arise from the presence of black mica. But this mineral is also either white or brown, and is thus productive of corresponding differences in the colours of the granite into which it enters.

"The felspar is subject to a greater variety of hue than either of the other ingredients; and, as it is commonly the most abundant, it often regulates the colour of the rock. Dark red and white are the most common extremes of colour, and it is also found of various intermediate tints of red. Occasionally it is ochre yellow, pale grey, blackish grey, or nearly black, and, in one rare instance, green. It does not seem well ascertained whether those varieties which, like that of Labrador, disperse coloured light, belong to granite: in some instances, at least, it appears certain that the compounds which contain them appertain to the overlying or trap family.

"The quartz of granite is most commonly white, or watery; and, being generally the next ingredient in proportion to the felspar, it also assists in many cases to determine the colours of the compound. Occasionally it is also grey and smoke-coloured, sometimes nearly black. It may be remarked, in concluding this part of the subject, that each of the three preceding minerals may exist of different colours in the same compound."

570. Granite and porphyries frequently appear in the form of veins occupying crevices and fissures in other rocks, and very often filling up narrow clefts in those rocks with which it is in contact. Many examples of this are seen in Scotland, and of one the annexed diagram (fig. 98) will give an idea, while innumerable others have been noticed and described in various districts. It has been customary with geologists to refer at once all these to a kind of injection of the porphyry while in a state of igneous fluidity; and appearances have been triumphantly referred to showing change in the adjacent rock, and thence assumed to afford convincing proof of the igneous nature of the change. Now, however, that we know how similar are the effects of slow chemical action at moderate temperatures to the rapid action of great heat, and how little the changes produced really require the interposition of melted rock, much more careful and minute observation is needed before the subject can be considered as settled, and much must be done by the chemist on a large scale, and by observations of Nature in the field as well as in the laboratory, to assist the geologist in coming to conclusions.

Fig. 98.

Contact of Granite with Slaty rocks in Glen Tilt.
a. projecting fragments of granite.
b. enclosed fragments of slate.

571. Granite and the other rocks of the same kind frequently contain metalliferous ores, contained in veins chiefly parallel to each other, and forming series of variable interest. The metals in England from this rock are chiefly tin and copper; in South America, silver; and in the Ural Mountains, gold: but, elsewhere, many others are found. Many simple minerals also occur in these rocks, of which the following are the most remarkable, viz. :—Actinolite, Andalusite, Apatite, Beryl, Chrysoberyl, Corundum, Emerald, Epidote, Graphite, Idocrase, Iron oxide, Iron pyrites, Jade, Lapis lazuli, Schorl, Spodumene, Sphene, Stilbite, Topaz, Tourmaline, Tremolite.

572. Of all the altered and so-called igneous rocks that we have described, those of one group, including the older porphyries, many

basalts, and many important trachytic masses, are either less manifestly bedded than the others, or are so extensively developed that their thickness cannot be determined. They also exhibit little or no mechanical structure. It is such rocks that have been regarded by many geologists as the solid framework or skeleton of the globe, and have been named *Primitive, igneous,* or *erupted,* and by Humboldt *Endogenous* rocks. They were also called by the early geologists *Plutonic,* and by Sir C. Lyell *Hypogene,* all these terms expressing the opinions held as to their origin. Some, however, both in former times and now, have been inclined rather to consider the possibility of all these being really but different forms of such substances as make up the more distinctly mechanical rocks—we mean the sandstones, limestones, and clays, and the substances occasionally associated with them. We do not now wish to discuss the question, but merely let the reader understand that the theoretical views alluded to are not quite unquestioned, and that many additional facts and careful deductions from them are still needed in this much neglected department of geology.

573. "The following account of what he regards as *endogenous rocks*, given by Humboldt, in his "Cosmos," will be useful as noting and defining some varieties of these rocks not before mentioned. He considers the whole group as separable into several series of rocks:—

1. *Granite* and *Syenite* of very different ages, the granite often the more recent.

2. *Quartzose porphyry*, frequently imbedded as veins in other rocks. The matrix is usually a fine-grained mixture of the same elements as those which form the larger disseminated crystals. In granitic porphyry, which is very poor in quartz, the feldspathic base is almost granular and laminated.

3. *Greenstone*, or *Diorite*, granular mixtures of white albite and dark green hornblende, forming *Dioritic porphyry* when the crystals of albite are disseminated in a compact paste. The greenstones, either pure, or, as in the Fichtelgebirge, containing laminæ of diallage, and passing into serpentine, have sometimes penetrated, in the form of beds, between ancient strata of green argillaceous schist ; but they more often traverse the rock in the form of veins, or appear as domes of green stone, analogous to domes of basalt and of porphyry.

Hypersthene rock is a granular mixture of Labrador feldspar, and hypersthene.

Euphotide and serpentine, containing sometimes, instead of diallage, crystals of augite and uralite, and thus becoming nearly allied to a more abundant, and, I might almost say, a more active eruptive rock, viz., augitic porphyry.

Melaphyre, and the porphyries containing crystals of augite, uralite and oligoclase, to which latter species the celebrated verd-antique belongs.

Basalt, containing Olivine and its elements (which treated with acids, give gelatinous precipitates), Phonolite (argillaceous porphyry), Trachyte and Dolerite : the first of these rocks is partially, and the second always divided into tabular laminæ, which gives to them an appearance of stratification, even when covering a large extent. Mesotype and Nepheline form, according to Girard, an important part in the composition and internal texture of basalts. The nepheline in basalt reminds the geologist of the *Miascite* of the Ilmen mountains in the Ural, a mineral which has been confounded with granite, and which sometimes contains zircon ; it also reminds him of the pyroxenic nepheline discovered by Gumprecht, near Lobau and Chemnitz.*

* Cosmos, Sabine's Trans. vol. i. p. 240.

574. It would not be right to conclude this chapter, in which we have endeavoured to prepare the reader to exercise an independent judgment in the matter of igneous and metamorphic rocks,—without referring to the experiments of Mr. Gregory Watts on the result of slow cooling of old lavas, and the apparent tendency to reform in crystalline arrangement when the rate of cooling was comparatively slow. The experiment was somewhat imperfect, and on a small scale, and perhaps in some respects has proved too much as well as too little to satisfy speculative geologists, but we are not aware that it has since been repeated. The quantity of material was about seven hundred weight, and consisted of basalt from the rock called Rowley rag in Staffordshire.

"The mass was placed in a reverberatory furnace, and exposed to the intense heat which is obtained in that way. It was found to melt with a less degree of heat than would have been required by an equal weight of pig iron, and as it melted it was allowed to subside into the deeper part of the furnace in the form of a liquid, but rather tenacious glass. A portion of it being then taken out and suffered to cool, retained the character of perfect glass. The remainder of the mass was left in the furnace, and was cooled very gradually, not being extracted for eight days. It was then cold externally, but still retained a considerable degree of internal heat. The extreme irregularity of its shape caused it to be so differently affected during the cooling that many peculiarities in the arrangement of bodies passing from a vitreous to a stony state were thus exhibited in a very remarkable way.

575. "The first result,—that of the rapidly cooled basalt resembling obsidian, or volcanic glass, is interesting and important, as it identifies two minerals exceedingly unlike in appearance and texture. The other results obtained from examining the cooled mass are also interesting.

"The first tendency towards arrangement in the particles of the fluid glass was exhibited in minute globules thickly disseminated through the mass, and where the arrangement extended a little further the mass was observed to be compact, to have an even conchoidal fracture, and it was then of a dark chocolate colour and greasy aspect, and resembled some varieties of jasper in its opacity and compactness.

"But the temperature favourable to the internal arrangement of the particles being continued as in the thicker portions of the mass, another change commenced, and a still greater advance towards stony texture was observable. This next step took place by a fibrous radiated structure exhibited in connexion with a tendency to spheroidal concretion, the centres of the formation of the spheroids being comparatively remote from each other, and not intermingling when two come in contact, but compressing one another, thus showing the nature of those conditions under which the columnar structure becomes superimposed; this latter being clearly only a particular form of the spheroidal structure.

"The next change that took place appears to have arisen from the fibrous structure of the spheroid becoming compact, so that the internal character of the mass was more decidedly stony, and possessed great tenacity. Its colour was now black, and it was quite opaque, but a continuation of the temperature appeared to render the mass more granular, and its colour more grey, while the molecules arranged themselves into regular forms, the whole mass becoming pervaded by crystalline laminæ, polarity being indicated, and the commencement of crystallization clearly taking place.

"The cavities at this point began to exhibit regular crystals projected from their walls, and this went on until the mass became porphyritic, and ultimately the whole a congeries of crystals."*

* Phil. Trans. for 1804, p. 279, *et seq.*

576. Referring once more to the analyses given in several former paragraphs, the reader, if his attention should be turned to the chemical bearings of the science of geology, will not fail to notice the importance of duly estimating the extent to which isomorphism may account for the varieties presented in the composition of the several simple minerals to which the crystalline rocks most nearly approximate. In the case of soda and potash this is remarkably the case, there being few instances where either of these bases is present without the other. Lime and magnesia, and sometimes oxide of iron, replace each other in like manner, while sometimes water takes the place of some of the usual component parts. In all these cases the difficulties of obtaining any exact idea of the nature of rocks are infinitely increased by the fact that it is only in crystalline minerals that any approach to uniformity of composition can be traced; while on the other hand the usual materials presented are amorphous and massive, and loaded with accidental matter, masking and obscuring the true nature of the fundamental rock.

577. In addition to the difficulties thrown in the way of the geologist by the infinite diversity of form presented when the same elements are mingled in different proportions, and the substitutions that take place of one element for another, we must also take into consideration the obscurity that at present hangs over the whole question of the composition of rocks, in consequence of our ignorance of the essential conditions under which chemical action may take place. The apparent ultimate identity of heat, electricity, and chemical force would suggest the possibility of many changes even in solid masses of rock when removed from the earth's surface below the stratum of invariable temperature, provided only time were granted to sufficient extent. Such changes might simulate, or even be actually identical with, those really produced in other places by very high temperature acting for a shorter time; while the ceaseless course of magnetic currents through the external film of the earth cannot but have great influence on every form of matter exposed to its influence. There are, however, some changes that, according to the present state of knowledge, we are bound to suppose must be produced by exposure to great heat, but which, on the other hand, chemical action without the rapid development of heat might avoid, and the fact of the existence of metamorphic rocks in which no such changes have supervened, seems to point to the necessity of reconsidering the whole subject of the so-called igneous and metamorphic rocks. We can imagine nothing more worthy of the attention of the physical chemist than to obtain and record facts bearing on these interesting problems concerning the earth's history.

CHAPTER XII.

ON THE STRUCTURE AND MECHANICAL DISPLACEMENT OF ROCKS.

578. HAVING in the preceding chapter explained to the reader the nature of rock masses, and the circumstances under which they may have been accumulated, we come next to consider the actual state in which we find them, or, in other words, their *structure* and *position,* two conditions, a knowledge of which is of the highest importance to the practical man, and on which all accurate knowledge of the principles of physical geology must be based.

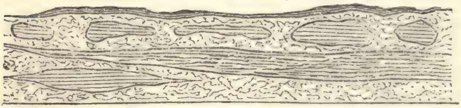
In describing the structure of rocks, we are obliged to use certain terms, already defined as regards mineralogy, but now to be employed in a more extended sense. Thus the *lamination* which in simple minerals is easily distinguishable as a distinct and well-defined character must now be regarded as extending through whole rocks in infinitely varying degrees of perfection. So also *Cleavage,* which is a character determining certain minerals, and enabling the crystallographer to discover the ultimate simple form of many rough and apparently shapeless specimens, here assumes a wider range, and becomes only a kind of lamination; while spheroidal and columnar masses are exhibited on the grandest scale, and we have conglomerates which put on every appearance of aggregation, from the mere heaping of dissimilar materials to the perfect association exhibited in true porphyries. It will be the object in this chapter to explain the details of structure as a fit conclusion to the account given of the composition and displacement of rock masses.

579. The only essential points of structure may be conveniently denominated *concretionary, prismatic, laminated,* and *porphyritic.* Each includes several varieties, and each is frequently referred to by geological writers under distinct names. All are more frequent and more manifest in rocks of crystalline or semi-crystalline texture than in those retaining distinct marks of their mechanical origin; but most of them may be recognised in all rocks to some extent.

580. Any accumulation of similar mineral matter in irregular masses included in other rocks, or any condition of a rock in which it tends to separate into spheroidal parts with or without concentric arrangement, must be referred to the kind of structure called concretionary. The more regularly the separate aggregations are arranged, the more clearly do they admit of description and definition; but they are not necessarily concentric in any case, nor are they always greatly different in their nature from the enclosing rock.

Concretions are not generally crystalline throughout their mass, though they sometimes contain crystals either in veins or disseminated. Globular or reniform concretions are found in limestones, sandstones, and clay, in almost all conditions of these rocks; while the more complete and perfect spheroidal structure characterises basalts, granite, and other rocks called igneous. Some concretions are represented in the annexed diagram (fig. 99).

Fig. 99.



Lenticular masses and nodules.

581. "The forms of concretions are various; they are sometimes nearly or absolutely spherical, in which case they touch by points only, and the intervals are filled by the same or by another substance. Examples of this are to be found in some siliceous schists and in some limestones.

"In other cases, by compressing each other they become oblate or indented, or assume various irregular shapes; and they thus sometimes form a mass which presents an aspect as much granular as it is concretionary. Some of the shales which are found in contact with trap rocks present examples of this peculiar structure. Such concretions further possess at times a distinct lamellar or a radiated structure; and in one rock (pearlstone) they sometimes contain a central particle of another substance.

582. "Rocks of this structure often acquire a botryoidal surface after exposure to the weather; and in some instances this concretionary arrangement is so concealed in the apparently uniform fracture of the rock, that it is only distinguishable under these circumstances.

"In the cases to which the preceding remarks apply, the general structure of the rock is concretionary throughout. The concretions are also of limited size, varying from that of poppy-seed to the diameter of an inch: but in other instances the concretionary structure is confined to particular parts of a rock, or insulated concretions are imbedded in an uniform mass. Such concretions are commonly of large size, and generally in the form of oblate spheroids. In some rare instances they are attached in pairs by a cylindrical stem; in others they are cracked on the surface into polygonal forms, which are consequently frustra of pyramids."*

583. But, in addition to these examples, many basalts and granites are absolutely converted into a mass of concentric globes of various dimensions but with no interstices; and some limestones, containing much carbonate of magnesia, exhibit large heaps of detached and

* Macculloch's "Classification of Rocks," p. 125.

hard spheroids of carbonate of lime, separated only by magnesian sand. These abound in the magnesian limestone of the coast of Durham, where they are accompanied by very singular concretions of other and more complicated forms, some being honeycombed, others concentric, and others laminated.

The most remarkable instances of concretionary structure that have yet been described are seen on some parts of the coast of Durham, where the magnesian limestone forms bold cliffs, which appear as if made up of an irregular pile of cannon balls. In this case, however, the carbonate of magnesia forms but a subordinate part of the rock, the concretions themselves consisting of carbonate of lime; and it would seem that, during the process by which the concretionary structure was effected, the magnesia was almost entirely separated, and left in the form of dolomitic or magnesian earth.

The curious spheroidal masses above alluded to are found associated with the laminated variety of magnesian limestone; and, on separating the beds, the laminæ are often seen not to be continuous, but made up of circular plates, running into one another. In this case the discoid forms of the laminæ indicate a tendency to aggregation about different centres, even when, owing to some cause, the operation could not develope itself in a vertical direction.

At the planes of separation, however, between two of these laminated beds, the concretions are more perfect, and approach the spherical form; the spheroidal masses impress both the upper and lower surfaces of the beds with which they are in contact; and the rock exhibits at one and the same time an earthy, a crystalline, a laminated, and a spheroidal structure. It is clear, therefore, that the concretionary form has been superinduced by some internal movement of the particles after their deposition.

When the concretions are more perfect they are sometimes grouped into beautiful and regular clusters, or by mutually penetrating each other, produce a number of grotesque forms, and occasionally a kind of honeycombed appearance, in which the small cells are arranged in horizontal lines, but still in concentric circles.

584. Many rocks offer extensive and numerous bands, which consist of the aggregated particles of some one mineral originally disseminated, and now separated from the mass. Thus in impure clays containing some carbonate of lime, calcareous nodules, not without a proportion of argillaceous matter, collect into distinct layers, as in the bed of clay through which the Thames makes its way; and in other clays, as the shales of the coal-measures, a carbonate of iron abounding with earthy impurities has been frequently formed in bands parallel to each other and at no great distance apart (see § 466). It is easy to perceive that these were not rounded before deposition, for they actually graduate into the enclosing rock; nor are they, as might be expected, concentric, but, on the contrary, they are generally laminated, the laminæ having the same direction as the great mass of the stratified rock of which they form a component part.

585. "The laminæ of the nodules are precisely parallel to the laminæ of the shale or marl in which they are enclosed, and little doubt can exist that they once constituted continuous portions of each other. The particles of calcareous matter have separated from the mass of marl, and have congregated together as we now see them. When we fracture these nodules through their centres and

parallel to the laminæ, we generally find some fossil, such as a fish, an ammonite, a nautilus, or a piece of wood, which seems to have formed the point of attraction to the various particles of calcareous matter that have assembled together. We might, therefore, infer that a fossil or other foreign body was always necessary to the production of the nodules; but, though such bodies are very commonly discovered in the centres of the nodules, they are not always present in them. The nodules have resulted from the aggregation of these particles in such a manner that the original laminated structure has not disappeared. If we conceive a particular line of deposit to have contained calcareous matter, which, though insufficient to constitute continuous limestone beds, was too plentiful to remain disseminated in the marl without endeavouring to arrange itself differently and in small masses, we may probably approximate to the truth. This view is borne out by considering how some of the upper beds of the lias limestones at the same place are circumstanced. They are evidently only extended lines of flattened nodules, which are, however, not generally laminated but compact, the arrangement of the particles having been more general.

"Now the latter structure in rocks, evidently mechanically produced, and even not calcareous, must be familiar to every geologist, though it is more prevalent where calcareous matter is intermingled with other substances. It is common in various sandstones, and is evidently the result of the attraction of certain particles among each other after deposition. The lamellar structure of nodules in siliceous sandstones is sometimes also observable, an aggregation of particles having taken place on the same principle as that above noticed in the lias, the cementing matter being sometimes calcareous, at others siliceous.

586. "Layers of nodules not lamellar, yet composed of substances which have separated out from the constituent parts of a mechanical rock after deposition, are common in many strata. The ironstone nodules of the coal-measures seem to have been thus produced. They also sometimes contain organic remains, such as portions of fossil vegetables; but as multitudes exist without organic exuviæ, they are evidently not essential to the formation of the nodules. The matter of nodules appears sometimes to have separated out from the body of the rock in which they are found in such a manner, that there has been a contraction of parts from desiccation in the interior, producing cracks which have subsequently been filled up by the infiltration of carbonate of lime.

"In the concretions commonly known as *turtle-stones, ludus Helmontii*, &c., the external parts have first become consolidated, so that during the desiccation of the interior, the internal parts were compelled to separate into cracks and shrink towards the circumference,

leaving the largest fissures in the innermost parts, as must necessarily happen. The subsequent filling up of the cracks is generally illustrative of the gradual accumulation of matter from the sides of such veins towards their middle portions. Coat above coat of carbonate of lime cover one another until the sides meet, highly crystalline matter filling up the irregular cavities which have often thus resulted. Nodules of this description, which generally exhibit no trace of either concentric or lamellar structure, are frequent in many clays and marls."*

587. Concretionary structure then generally involves some changes from the original conditions of deposit, but these run through an almost infinite gradation. In clays the concretions, as we have seen, consist of the impure and earthy carbonates of lime or iron, originally disseminated through the mass, but subsequently collected into definite masses. In limestones, siliceous concretions are more common, but sulphuret of iron is not rare, while in siliceous rocks, as sandstones, we find marl, gypsum, rock-salt, and other substances. So, again, in cavities which are not veins, we find concentric masses of iron and manganese oxides, and of carbonates of copper. On the surface of clays, such minerals as *Websterite* appear, and elsewhere the magnesian minerals form into concretionary masses. Fullers-earth and many described simple minerals, belong to the same group of phenomena, being segregated bands; and many instances of substitution observed with regard to organic remains, must be regarded as fundamentally of similar nature.

The following analyses† of red marl from the Old red sandstone of South Wales, containing cornstone (calcareous) nodules, and also of one of the nodules embedded, will illustrate the nature of the change when this segregation takes place. The rock originally must have contained a good deal of silicate of alumina and carbonate of lime, or in other words, must have been a chalky mud.

	Marl.	Nodule.
Silica	64·3	19·5
Alumina	21·1	7·2
Carbonate of lime	0·2	69·3
Peroxide of iron	9·6	2·2
Water	4·5	0·9
Traces of chlorine, &c., and loss	0·3	0·9
	100·0	100·0

588. Different as they may seem to be, there is little doubt that concretionary and prismatic structures truly pass into each other by insensible gradations. The former, when most complete, is seen in spherical masses, flattened, as if by pressure against each other:—the usual condition of what is called 'columnar basalt,' in many of the best known and most remarkable exhibitions of that rock. On the other hand, the prisms which are most characteristic of the second

* De la Beche's "Researches in Theoretical Geology."
† "Memoirs of the Museum of Economic Geology," vol. i. p. 63.

kind of structure, are also frequently rounded at the angles, and decomposition proceeding regularly from the surface towards the centre, lays bare the concentric arrangement which has been induced. But it is not always that the wear proceeds thus regularly. It often commences in several places at once, and tends to split the rock into coarse laminæ, and thus indicates lamellar instead of concentric arrangement. There is, however, this difference—that in the structure we are now describing, the forms approximate those of cubes, or rhombs, and represent a more advanced state of crystalline action than the former: and in most cases this advance is seen even in the texture of the rock and the nature of the contained minerals.

589 There may be considered to be two kinds of prismatic structure — the simple prismatic and the columnar, the former being usually observable on a much larger scale than the latter, and affecting such rocks as granite, crystalline limestone, quartz rock, and slate; while the latter is seen best in basalt, where the quantity of matter is by no means so considerable. All the rocks exhibiting either kind, contain occasionally simple crystalline minerals, and between interstices are found plates of quartz, carbonate of lime, sulphate of barytes, oxide of iron and manganese, native silver, native gold, platinum, and other metals. The structure of the rock itself is often distinctly crystalline; occasionally throughout, but more frequently as a confused crystalline, or amorphous and massive rock, in which crystals are embedded. Many terms are used to describe this condition of a rock, in which it splits more readily in one direction than another, and in all kinds of quarrying and mining a knowledge of its nature and amount is in the highest degree important. The *grain* of granite is of this kind. So also are the joints in most calcareous building stones, and the *sline* in coal, the latter material offering indeed excellent examples of this kind of structure, and being at the same time distinctly altered and presenting other crystalline characters.

590. " In the columnar structure, as the term implies, the prisms generally possess a considerable length in proportion to their breadth, and they are not limited to the quadrilateral form. In a few instances, owing to the extreme shortness of the prisms, the columnar passes to a tabular, or a lamellar and jointed structure; but the two are united under this head, in consequence of their general resemblance and of the undefinable line by which they are separated. Where the columnar structure is on a very large scale, it might be supposed to belong to that division which is included under the term of external configuration; but, in reality, it is properly placed here.

" The columnar structure is invariably aggregated. No instance is known of a single column, as there are of single spheroids, included in an amorphous mass. Pitchstone scarcely offers an exception, as

the small columns which it sometimes exhibits, are portions of lamellæ.

"As the prisms are often accumulated in a parallel manner, of the same length, and for a considerable space, they unite to form a bed, or pseudo-stratum; or else such a bed appears to be split into prisms, and that division generally takes place nearly at right angles to the leading planes. But as such planes are not necessarily parallel, so, in a mass of prisms, the lengths of these concretions will be found to vary in different parts.

"Not unfrequently the most regular columnar structure vanishes in the same continuous mass, and in a gradual manner. This takes place, either laterally or in the direction of the axis.

591. "In a columnar mass, the axes may be vertical, or inclined to the horizon at any angle, or horizontal; and, in these cases, it is implied that the prisms are straight, as well as parallel to each other. The parallel position is not, however, necessary. In a collection of prisms, they are sometimes found to radiate from some imaginary centre, or from more than one. In other cases, they are placed in various irregular ways and entangled together. In some instances such irregular prisms are found more or less accumulated, or dispersed and intermixed with the same rock in an amorphous state. When a collection of prisms is parallel and erect, with straight axes, and on a large scale, well known effects of architectural regularity are produced. These are exemplified in the Giants' Causeway, in Fingal's Cave in Staffa, and in many other localities.

592. "The prisms are not necessarily straight. At times they are slightly, at others, very conspicuously curved. Sometimes the same curvature affects a considerable associated number; or the prisms are then bent in a manner more or less parallel. In such examples, the general effect of regularity is not destroyed. In other instances the curvatures are variously opposed, or the bent are intermingled with straight prisms.

"A columnar mass is sometimes formed of a collection of short prisms, placed in a manner more or less parallel, but so that the extremities of some are in contact with the middle parts of others. In such cases they impress each other, and the effect of regularity in the structure of the mass nearly disappears.

"As the prismatic is united to the bedded form, so it occurs together with the concretionary; but, in the only instances known, the prisms are short and united with the amorphous mass. On the small scale, as in columnar ironstone, which is but a modification of shale, a collection of prisms is not only curved but sometimes minutely undulated.

593. "The prismatic structure is not limited to beds, or masses, but occurs also in veins. In this case the prisms are most commonly

at angles to the plane of the vein. But they have been also found to occur in a direction parallel to it, and either horizontally or vertically placed. The columnar structure is sometimes combined with the lamellar; and the lamellæ may either be parallel, or at right angles to the axis of the prism.

"In an aggregate of prisms, they are always found in contact, except in the case of an union with the spheroidal structure, when they are separated by empty intervals, or by intervals filled with another substance. The contact is sometimes such as to admit of the ready separation of the prisms; at other times, there is a partial or more complete coalescence.

594. "The sizes of prisms are various. In diameter or thickness they rarely exceed nine feet; and from that, they vary to one foot or less. In columnar ironstone (which, as a modification of shale, is here ranked with rocks), they are sometimes even less than the tenth of an inch, so that the mass becomes nearly fibrous. In length, they vary from 1 foot to as much as 300 feet, or even more; but when the length becomes so considerable, it is difficult, for want of access, to determine truly whether the single prisms of a mass are continuous throughout. The forms are equally various, from three-sided, upwards, even to twelve; but figures of four, five, and six sides, are the most common. Such figures are by no means regular, unless in a few accidental cases; and every modification of form may be found aggregated in the same mass. Nor are the sides of the prisms necessarily straight; being sometimes convex or concave.

595. "Prisms are sometimes continuous for a considerable length. At others they are divided by oblique or irregular joints. In many instances the joints are at right angles to the axes and occur at different intervals, from an inch to many yards. When such joints possess an average general distance varying from one to three feet, a considerable appearance of artificial regularity follows; and it must be remarked, that the most perfect and numerous joints occur in the most regularly formed columns. They are in some cases, as already noticed, so frequent as to produce tabular prisms, not reaching to or exceeding an inch in size.

"In the joints the surfaces in contact are sometimes uneven, at others flat, at others again, alternately concave and convex; and either of these forms may be found in the lower portion. In some remarkable examples of a lower concave surface, the angles of the inferior portion protrude in a point which covers a corresponding deficiency in the upper. In others, equally remarkable, the surface of a joint is marked by a channel parallel to its boundary and near the edge of the prism. The first of these is exemplified in the columnar traps, or basalts, the last in columnar ferriferous shale, or ironstone.

596. "In the smaller columnar structure the prisms are sometimes longitudinally striated; and, in some instances, further distinguished by protuberant rings or inseparable joints. Examples of this may be found in limestone, in jasper, and in argillaceous ironstone.

"In the act of decomposition, the portions of jointed prisms sometimes give indications of a lamellar structure, which, in the progress of desquamation, leaves a spheroidal nucleus, each successive lamina becoming gradually more regularly curved. This case is analogous to that which occurs in the common prismatic structure already noticed, and admits of the same doubts as to its real nature." *

597. The structure called laminated is either that which will be fully exemplified and explained in speaking of stratification, or else a more completely fissile kind called also *cleavage.* The latter will here need careful consideration. It is confined to slate rocks, and is greatly limited even amongst them, if we regard the term in its strict sense, for in many so called slate rocks, only a small proportion of the whole mass will be found to split in delicate and well-marked cleavage planes. Cleavage, however, often passes into a still more perfect foliation marked by distinct crystals on the planes of foliation, and this is the case not only with slates, but mica and hornblende schists, and gneiss.

598. In most rocks exhibiting cleavage there is some evidence to be obtained of stratification, and some proof of subsequent mechanical disturbance. It appears that generally the direction (*strike*) of cleavage planes is parallel to that of elevation or to the principal anticlinal axes of the district. In Wales, over more than two-thirds of the Principality, where slate rocks are abundant, this direction is between N.N.E. and E.N.E.; in the Lake district of Westmoreland and Lancashire, E.N.E.; in Devonshire and Cornwall it is generally W.S.W. to E.S.E. But it is chiefly in South America that these phenomena are presented on such a scale as to lead to a notion of their real extent; and there, Mr. Darwin informs us, that for a space of 300 miles on the shores of the Chonos and Chiloe Islands (lat. 41° to 46° S.), there is seldom a deviation of more than a point of the compass from a N. 19° W. and S. 19° E. cleavage strike, while the same direction is retained with little change over a very much greater range of country. In these cases there seems no complete coincidence between the strike of the cleavage and that of the strata, but the general range of the axis of elevation often agrees with the latter direction.

599. While the direction of the cleavage planes is thus constant there seems generally to be a wide and singular diversity both in the amount and direction of the dip or inclination. The angle of dip

* Macculloch's "Classification of Rocks," p. 129, *et seq.*

is generally high, but varies or oscillates from one side to the other of a vertical plane. The dip of the cleavage has manifestly no relation whatever to that of the beds, or to the changes of position which they have undergone, and not unfrequently on the two sides of the same mountain chain we find the inclinations opposite and converging downwards, the cleavage planes between them being vertical.

This is the case in the Alps and other mountain districts, and bears no doubt upon the general question of the forces involved in the production of the phenomena. In some cases, though not commonly, a second cleavage is found to have affected the same rocks, but this seems only a further exemplification of the metamorphism the rock has undergone.

600. It is highly probable, if not absolutely certain, that a process of change has gone on during a long period and to an enormous extent in all rocks, but especially those silicates of which alumina is the principal, and the other alkalies and iron the secondary bases. The effect of such changes has been to re-arrange the particles of the rocks, producing a new and perfect lamination in some one plane determined by local and external circumstances, and a less perfect, but recognisable lamination in a direction transverse to the principal one, tending to collect like mineral masses in these planes. Most of these planes will be found parallel to one principal line of direction, having distinct relation to the general elevating forces which have produced the existing physical features of the district, and have terminated when these physical features were firmly and permanently impressed on the earth's surface. What the cause may have been we will not here speculate, but that it was something more than mechanical, and something less than igneous, will, we think, be at once admitted by every one who has studied the phenomena however slightly.

601. The last important variety of structure is *porphyritic*, by which term geologists have agreed to denominate all rocks having crystals imbedded in a matrix. Granite, Syenite, and a host of other rocks are of this kind, and trachytes, basalts, altered slates, &c., may also be named as approximating to, if not actually exhibiting, a similar structure. Judging from the gradual change that appears to take place where schistose rocks have been long acted upon by crystalline forces, it would seem that one substance, as quartz, is collected into a tolerably pure, but amorphous and uncrystallized mass, while other substances more readily crystallizable find for themselves cavities in this matrix, and crystallize as completely as circumstances will admit. Thus, in basalts we find cavities filled afterwards with leucite and other volcanic minerals, sometimes *amygdaloidal*, the minerals occupying oval cavities (like almonds embedded in a paste), but often passing into true porphyry, the minerals being crystalline

and implanted ; while in South America claystone and clay slate exhibit perfect transition to a similar rock, and contain many rich veins of silver. Porphyries often contain a large proportion of felspar and felspathic minerals ; but it will be evident from the nature of the definition given, that they include a great variety of very different rocks so far as chemical composition is concerned. We do not dwell now at greater length on the structure characteristic of these rocks, believing that the explanation of the rocks themselves, which has already been given, is amply sufficient. We, therefore, quit the subject of structure and proceed to that which is only next in importance—namely, the mechanical conditions under which the various rocks occur.

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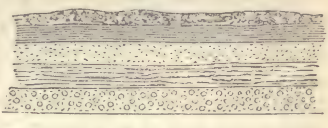
602. In whatever way rocks have been formed they exhibit certain phenomena of position, which are of the greatest possible interest in the science of Geology, and with which it is absolutely necessary that the student should be acquainted. We must consider these with reference to the various groups of compound mineral masses described in the last chapter, and shall endeavour to place the subject before the reader in such a manner that he may obtain a distinct and practical idea of them.

Almost all rocks, either on a large scale or in detail, have some appearance of superposition, for they may either be seen reposing on other rocks, or other rocks repose on them. In the case of granite and other porphyritic rocks, and in basalt, the materials are generally superposed in thick masses without parallel surfaces, and without regularity of arrangement, while the masses themselves rarely exhibit any structure approaching to the nature of lamination. In schistose rocks, and in most rocks manifestly of aqueous origin, the whole mass is found to be divided into laminæ, beds, or strata, which vary much in thickness, and in the minuteness to which such structure can be traced, but which fully justify the terms *laminated*, *bedded* or *stratified*, as applied to them. Perhaps the simplest conceivable case of such stratification is that exemplified in the annexed diagram (fig. 100), where a number of substances are represented as lying one upon another in regular and unbroken order. These substances may be of different kinds, or nearly the same kind, but the arrangement gives them a common character. Again, some of them, as those represented in the diagram by lines, may themselves be laminated like the thin bands of the same bed of lime marl, while others may be merely

Fig. 100.



loose particles, as of sand, or masses of clay or gravel confusedly heaped; but so long as they present in section the appearance shown in the diagram, they may safely be regarded as regularly stratified, and exhibiting *conformable* superposition.

603. The extent of accumulations of this kind is a matter not altogether to be neglected. When the eye can at once take in a series and recognise it as stratified little doubt can arise, but when the same rock occurs of great thickness and over a wide extent of country, presenting little internal lamination, or lamination which is not that of the original bedding, practical difficulties arise, and the rock may be described by one observer as stratified, and by another as unstratified. The approximate parallelism of surfaces that marks true stratification it is also very difficult, if not impossible to define. A subject, therefore, so simple as the position of one mass of material with respect to another, may, when considered and discussed on the large scale of Nature, become invested with unexpected difficulties, and needs some careful study, and a habit of accurate definition to comprehend and describe properly.

604. Stratification may be, and is, in ordinary cases, the result of successive superposition, but the same appearance may be presented by a semi-crystalline structure. Thus granite, which is sometimes really bedded, alternating with schists and porphyries, occasionally shows a rough kind of lamination which is due to concentric arrangement of the whole mass, and the curvature of this rough ball or fragment being extremely small on account of the vast dimensions of the spheroidal mass, the curvature of the laminæ is not observable. Similar concentric arrangement in the case of basalt is frequent, but the balls or spheroids are of comparatively small size.

"Near Monte Video, where the stratification, as it would be called, of the metamorphic series, is in most parts particularly well developed, being as usual parallel to the foliation" (a well-marked phenomenon in the mica schists, hornblende slates, gneiss, and other rocks of that kind in the district), "a mass of chloritic schist netted with quartz veins is entangled in gneiss in such a manner as to show that it had certainly originated in some process of segregation. Again, in another spot, the gneiss tended to pass into hornblendic schist by alternating with layers of quartz; but these layers of quartz almost certainly had never been separately deposited, for they were absolutely continuous with the numerous intersecting veins of quartz. Hence I am led to believe that most of the so-called beds are of the nature of complex folia, and have not been separately deposited."*

605. The strata formed by the deposit of materials of various kinds from suspension and solution in water, although the types of stratified rocks, exhibit only approximate parallelism even under the most favourable conditions of formation, for they must necessarily terminate somewhere, and cannot have been distributed with perfect uniformity over a sea bottom which has itself in many cases been very uneven. Strata thus *thin out* and occasionally on the other

* Darwin's "South America," p. 166.

hand are much thicker than usual in particular spots. Generally it will be found that thin beds are not so persistent or uniform over large areas as those of greater magnitude, but many exceptions are known to this law; and the magnitude of a deposit in vertical thickness is by no means to be taken as a measure of its horizontal extension. Examples of the thinning out of deposits are given in diagram 99, and also in the subjoined figure (101).

606. It is not often the case that the same stratum can be continuously traced at the surface to a very great distance in two dimensions; but when such observations can be made, it is still more seldom that the bed is found to have precisely the same appearance and character. The thinning out already alluded to is not always the consequence of the termination of a deposit by what we may call exhaustion of the supply, but may also (as in fig. 101), be the result of the form of bottom on which the deposit was made.

Fig. 101.

Deposits on a sloping line of coast.

607. Regarding the various ways in which matter is now being accumulated in river beds and lakes, and on coast lines, it is clear that some of these deposits will be nearly horizontal; others very irregular at bottom, adapting themselves to the form of the receptacle in which they are placed, but approximately horizontal at the upper surface; others sloping parallel to the gradual incline of a shelving coast line; and others in a basin-like form inclining from each side towards the middle. These conditions are seen in the slight sectional diagrams annexed, which hardly require any further description. They afford examples of conformable stratification; although in one (fig. 103), the form of the surface in which the upper deposits were accumulated, exhibits an amount of mechanical action, no doubt of water, which marks an interval of time elapsed between the termination of one deposit and the commencement of the next. The middle

Fig. 102.

Fig. 104.

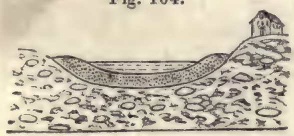
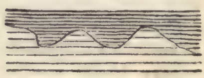


Fig. 103.



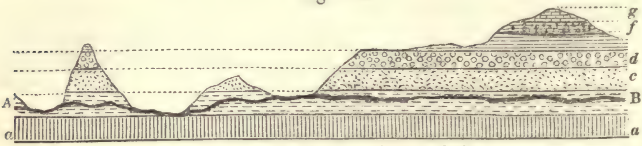
Examples of various kinds of Stratification.

diagram (fig. 104), demands some notice, as showing also the mechanical action of water, first eating out a channel and afterwards filling up that channel with transported material. Valleys are in this way often formed and partly obliterated; and such valleys, some-

times called valleys of denudation, or valleys of erosion, are carefully to be distinguished from others that we shall have to describe presently, and in which the original formation is altogether different.

608. If we imagine the whole external crust of the earth to have been originally covered by concentric layers deposited from water, and that the present outline of the surface has been produced by the partial removal of these coats, we might represent a section through some district by the diagram (fig. 105), where we may take (a) as the

Fig. 105.

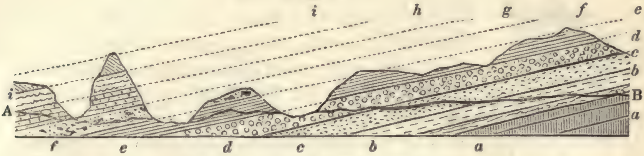


Horizontal strata laid bare by denudation.

lowest of the layers that can be observed, and others b, c, d, e, f, g, as various overlying strata of nearly the same thickness. If each of these layers have an average thickness of 4000 feet, the whole height above the surface required to lay bare these strata would be something more than 16,000 feet, and a nearly horizontal line on the surface, would hardly expose more than one deposit, as seen by the irregular line, AB. But if the beds, instead of being pared off by such a line, were partly left, we might have the broken surface of a country forming a series of hills, cliffs, and mountains, the latter rising to a height of 16,000 feet or more, really exhibiting a range of strata to that extent. If drawn to the scale of nature, however, it would be found that a very wide tract of country would be needed by such an exhibition, were the structure as we have assumed. But let us next suppose, that owing to the action of some powerful disturbing forces, not dissimilar, perhaps, to those now elevating parts of the Continent of Europe, the layers originally parallel have been tilted up in particular places, until they make an angle of above 12° or 15° with the horizon before irregularities of surface were produced. These being supposed to present the same physical features as before, we shall now find some curious results: first, that the broken surface may present even smaller variety of deposits than before; but secondly, that a nearly horizontal line on the surface will *of necessity* intersect a large number of different beds. In the diagram (fig. 106), where these conditions are illustrated, the line AB will be seen to expose, in a small horizontal distance, the whole number of beds which required in the former case an elevation of more than 16,000 feet; and this result of a comparatively small amount of vertical displacement, introduces us, therefore, to the consideration of those frequent cases in nature where a multitude of beds come to the surface

one after another (being technically said to *crop out* or *basset*), as we advance in a direction at right angles to that of the axis of elevation, while in the direction of that axis the same beds are continued.

Fig. 106.



Inclined strata laid bare by denudation.

Thus it is that when beds have been exposed to mechanical displacement, they may be described as having a true direction or bearing (which is the same as that of all horizontal lines upon their surfaces); and also an inclination to the horizon (which is that of a line at right angles to this direction). The direction of the bed is called, in Geological language, the *strike*, and the inclination, the *dip*.

609. Many causes have been assigned for the alteration of level observed to have taken place in beds which must originally have been nearly, if not absolutely, horizontal; but of the fact of such alteration at various times and to very different amounts, innumerable observations in all parts of the world leave no doubt. Many peculiarities of appearance are presented in nature, manifestly dependent on alternations of elevation and repose, combined with very unequal rates of deposit, and constant changes of the matter deposited. Some of these must now be described and explained.

The mechanical displacement of rocks by movements acting from below, has been constantly going on, affecting all deposits, and producing every conceivable amount of modification. The disturbing force has sometimes acted at a point, but this must be regarded as the exception; and if we consider what has been said in a former chapter on the distribution of active volcanoes, it will appear that lines of elevating force are far more usual than mere points of elevation. The result of elevation of this kind, when it does occur, is, however, to produce a kind of dome, or central point with beds dipping from it in every direction. This is called sometimes a *quaquaversal dip*; and "craters of elevation," or enclosed valleys, generally of circular or oval shape, with a small central elevation and rings of higher ground forming rims, are the result of elevation of this kind. The diagram annexed (fig. 107), shows very sufficiently the general succession of valleys and ridges; which, when the section is the same in every direction, would form a true elevation crater.

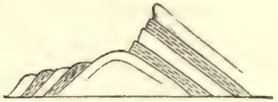
610. A far more usual mode of action of subterranean force is to cause a general elevation and fracture more or less complete, along a

line frequently of great extent. The section at right angles to this line or axis of elevation, is seen in the little diagram annexed (fig.

Fig. 107.

Section in any direction across an elevation-crater.

Fig. 108.



Section across an anticlinal,—the beds fractured.

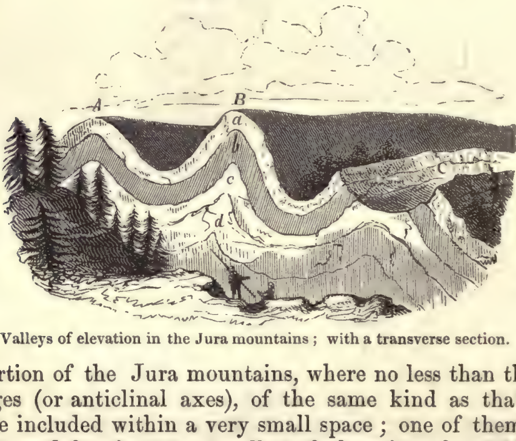
109), which simply marks the bending of the strata. If, however, as must generally happen, the upper beds, unable to resist the force of extension, are cracked and separated by an interval, we have then the case illustrated in another sketch (fig. 108). From these diagrams, however rough, the student cannot fail to discover the simplicity of the mechanical laws brought into action; and it will be observed that we have not assumed any particular force or mode of disturbance, but merely take for granted the admitted fact of there being some cause of pressure from beneath, and some force constantly acting. The line of direction of the elevation, or the direction of the ridge, is in these cases technically called an *anticlinal axis*.

Fig. 109.

Anticlinal axis.

611. As a picturesque example of the same kind of action, we must next direct attention to another diagram (fig. 110), represent-

Fig. 110.

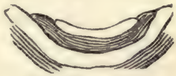


Valleys of elevation in the Jura mountains; with a transverse section.

ing a portion of the Jura mountains, where no less than three parallel ridges (or anticlinal axes), of the same kind as that figured above, are included within a very small space; one of them (c) being broken and forming a true valley of elevation, the strata inclining on each side *from* the axis of the valley; while, between the

others (A, B), is also a valley, but in this the beds incline on each side *towards* the axis, as shown in the next diagram (fig. 111). The line of the valley is in this latter case called a *synclinal axis,* or simply a *synclinal,* from the position of the beds. The wave-like undulations of the beds are well shown in fig. 110, where the small letters, *a, b, c, d,* mark the different strata whose course can readily be traced across the axes of the valleys and hills. The synclinal may manifestly be due, as in the first diagram, to the beds being affected by two anticlinals ; or it may arise, as shown in the other, from the beds having sunk down into a hollow, owing to want of support.

Fig. 111.



Synclinal axis.

612. When the elevation of a series of beds takes place on a line or axis, the tendency will be to break the brittle beds, and stretch those in any way elastic. It is important that the student should be able to appreciate the nature of the effect produced in different cases, and in fig. 112 is given a sketch of the first fracture when the beds

Fig. 112.

Fracture of the surface-beds on elevation.

are strained beyond endurance. The ends of the beds must be kept down by the heavy pressure of overlying strata, and the beds themselves possess a certain amount of tenacity, to admit of such a result as that figured ; but slow and long continued upheavals cannot fail to offer abundant opportunities for similar appearances. The elevation having proved sufficiently powerful to crack continuous bands of sandstone, limestone, or other hard rock, the work of further destruction would proceed very rapidly, and, after a short time, little would be left of the broken portion, beyond some new rock formed at a distance out of the transported fragments.

613. Complicated results of elevation on an axis, or on two or more parallel axes, must sometimes occur. One of these is figured in the annexed sketch (fig. 113), where a mass, *a*, of the fractured strata, becomes the summit of a hill thus formed, presenting the appearance of a repetition of beds, of which it was once an integral part.

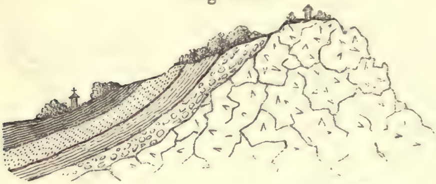
Fig. 113.

Outlier resulting from a double anticlinal axis.

614. Beds that have been disturbed, and thrown into a new position by pressure from beneath, do not always offer the phenomena of an anticlinal axis ; they are sometimes thrown off on one side of a mountain chain in the manner indicated in the annexed figure

(fig. 114), the igneous rock of the chain being in the centre, and occupying the chief elevations, while the beds on the other side have been scarcely disturbed. The angle which the beds make with the horizon in such cases, varies indefinitely from nearly vertical to very small quantities; but most frequently the inclination is not only sensible but considerable in the immediate vicinity of the culminating ridge. It is evident that distinct fracture along an extended line of country must have preceded such a lifting of part of a series of beds without the contemporaneous elevation of the other part.

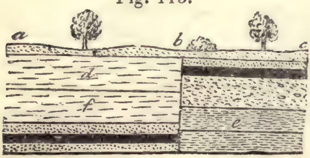
Fig. 114.



Highly inclined deposits on a mountain side.

615. When the actual continuity of beds has been broken during or in consequence of an upheaval, and when no underlying rock forced through the mass conceals one side of the fracture, it is still often the case that the edges of the fractured beds do not reunite, the consequence being that some permanent displacement is produced. Thus, in the case represented in fig. 115, the surface deposit of soil, *a b c*, is seen to cover uniformly beds which are not continuous; and, although the surface is now level, there must have been once a hill formed of the whole thickness of the beds *d*, *f*, between the points *b*, *c*. The name *fault*, *slip*, or *throw*, is given to such a displacement when of small extent, and instances occur very commonly in many districts. Certain rocks seem to exhibit faults more frequently than others; and, probably, the same amount of disturbing force has affected rocks very differently. Faults, when of very large extent, are sometimes called *dykes*. They vary in magnitude from a few inches to many hundreds or even thousands of feet.

Fig. 115.



616. We have hitherto been considering only those kinds of stratification that are conformable, or approximately parallel to each other; but it frequently happens that not only has an interval of time elapsed between consecutive deposits, but a certain amount of

Fig. 116.

Fig. 117.

Unconformable stratification.

displacement of the lower stratum has also been produced. Such a case, in its simplest form, is represented in fig. 116, where horizontal deposits have accumulated about a projecting fragment of inclined strata, and other more complicated forms of the same condition, are seen in fig. 117, where the lowest mass, after great displacement, has received deposits on two sides of a hill or prominence,—the new deposits being parallel to the principal slope of the hill in each case.

617. When horizontal deposits have taken place on the denuded surface of other strata, after these latter have become highly inclined, the result represented in fig. 118 is obtained; and in journeying

Fig. 118.

A valley of denudation in inclined strata filled up with horizontal deposits.

over a district nearly level at the surface, some knowledge of structure and some practice in observing, is needed to discover the true state of the case. When, however, the clue is once obtained, no further difficulty exists, and many apparent anomalies in drainage are to be explained by reference to this arrangement, which is more common than is often supposed by engineers and agriculturists.

618. Horizontal deposits, covering others inclined at a considerable angle, have sometimes been partially removed by denudation; a portion of the inclined bed being carried away at the same time. A case of this kind is seen below (fig. 119), and a portion of the overlying

Fig. 119.

A valley of denudation cut through unconformable strata and producing an outlier.

rocks, called then an *outlier*, seems to be, and is entirely, detached. Here again very marked results are produced on the drainage of the district, and the true conditions are masked and obscure. Other outliers are represented in a former diagram (see figs. 105, 106).

619. While speaking of irregular and unconformable masses, we

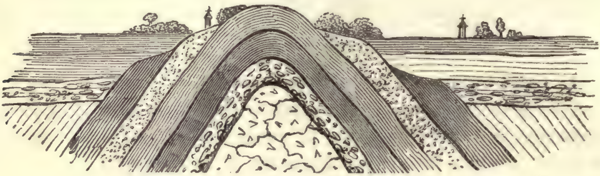
must include such cases as that shown in fig. 120, which represents in section what is sometimes seen in chalk or other rocks, chiefly calcareous, where a mass of gravel or other rolled material collects in clefts and cavities, and forms considerable deposits, overlying them unconformably, and sometimes valuable as metalliferous ores. Many other examples of unconformable superposition may be observed, some on a small, others on a large scale; but those we have described are the principal ones that have an important practical bearing.

Fig. 120.

Heap of detritus filling up clefts and cavities.

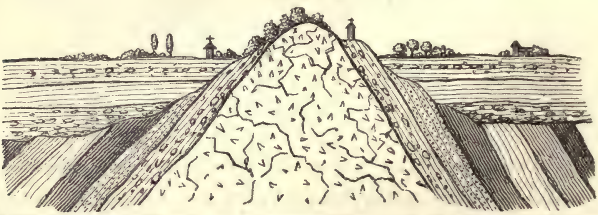
620. We next have to consider two cases of considerable importance in mining districts, where the unconformable superposition of horizontal deposits obscures or entirely conceals the existence of anticlinal axes and other local disturbances, the results of elevation. In fig. 121 a number of deposits are represented as elevated, and forming a marked and prominent ridge; the uppermost have been removed by fracture and denudation, and then the whole has been covered up nearly to the summit by various horizontal beds. In passing over the country only the small conical hill of one of the uplifted strata would be visible, but valuable beds of limestone or other material may evidently exist concealed at a small depth. In the other case represented in fig. 122, a hill of igneous rock (basalt or granite), appears at the surface, and the deposits flanking the central elevated

Fig. 121.



Horizontal deposits masking an anticlinal axis.

Fig. 122.

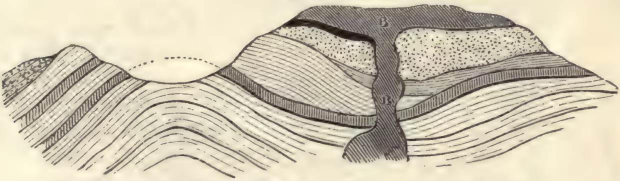


A hill of igneous rock penetrating horizontal deposits, and indicating old rocks inclined at a high angle.

mass are still more completely concealed than before. This and various other cases of concealment by unconformable superposition require, as we have already said, some insight into the laws of arrangement of strata to understand and apply. They are cases extremely common in some large districts.

621. Appearances resembling unconformable superposition are sometimes induced near igneous rocks, when these are either at the surface or embedded amongst other rocks at no great depth. A good instance of the first condition is seen in figure 123, where

Fig. 123.

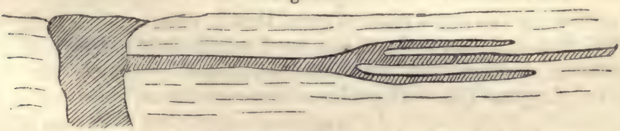


Protrusion of basalt, the basalt also overlying rocks at the surface.

also other results of disturbance, and a valley of elevation are shown. The mass marked B, is here supposed to be the filled-up channel through which a melted rock, such as lava, has been forced. The lava having first spread out at the surface, and afterwards cooled, we have one of those instances of capping of hard basaltic rock, of which many occur in India, others at the Cape of Good Hope, and some in Ireland, on the Antrim coast. Instances are not wanting of a similar kind in various parts of England; and when the basalt is harder and decomposes less readily than the rocks around, these tabular masses often affect the landscape to a very remarkable extent.

622. When masses of basalt or granite are not evenly spread out at the surface, but contained in the mass of a mechanical rock as in figure 124, the horizontal portion is called an "injected vein," and

Fig. 124.



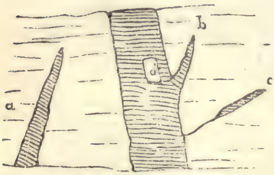
Vein of trap in sedimentary rocks, Isle of Skye.

the vertical part is a "dyke." In other cases, as in fig. 125, veins give off small ramifications (*a*, *b*, *c*), and within the principal band of igneous rock are found small fragments (*d*) indicating a condition by no means easily explained on any hypothesis, and perhaps least of all by that most commonly assumed—the former igneous fluidity of the contents of the dyke. However this may be, cases of in-

cluded rock, offering accurate resemblance to the containing mass, and having manifest connection with it, are proper to be mentioned here while describing the mechanical relations of rocks generally.

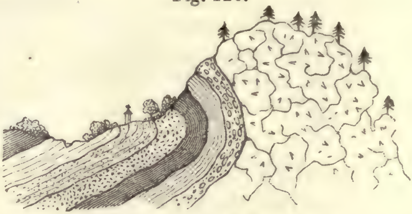
The following account of the most remarkable basaltic dyke in England will give an idea of the extent and magnitude of some of these phenomena. This dyke commences in the southern part of the Newcastle coal-field, near Bishop's Auckland, in Durham, and, running in a direction a little south of east, crosses the Tees, and cuts through the secondary rocks of Yorkshire, being traceable for a distance of nearly sixty miles in a straight line. It then communicates by a cross dyke with a third dyke almost equally extensive, and parallel to the first, extending from Brampton to near Alnwick, in Northumberland, and, like the others, passing through all the rocks of the carboniferous system.

Fig. 125.



Ramifications of trap vein.

Fig. 126.

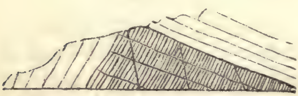


Reversion of dip in inclined strata.

623. The angle of elevation of disturbed strata in tolerably level countries rarely approaches to a right angle ; and it is only in mountain districts, or where there are marked and considerable local disturbances that this limit is at all reached. Still it happens that not only are rocks fairly set on end, or made to exhibit vertical stratification, but sometimes they are turned over so as to dip for a time in a direction exactly contrary to that generally presented. An example is given in figure 126, and the gradual recovery of the true dip is there easily seen. In some districts cases of this kind are troublesome and difficult to make out, and serious mistakes concerning the relative positions of rocks have arisen in consequence of them. They can only be safely decided on by following the beds on the strike till the more natural condition is seen.

624. The last example of the mechanical displacement of rocks apparently stratified that we shall here refer to is represented in the annexed diagram (fig. 127), where strata are seen to have two well-marked directions with an intermediate portion of doubtful bedding. Examples of this kind are in most cases due to crystalline action, but when noticed they require careful and minute examination. The student cannot be reminded too often of the necessity of learning accurately in every instance the true struc-

Fig. 127.

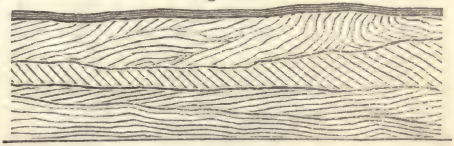


Doubtful stratification.

ture of a district under examination in all its details, for this knowledge will always be found to repay the labour and time it has cost, and will greatly assist in applying geological observation to important practical uses. Structure is of all subjects in geology that to which least attention is generally paid, and which, notwithstanding, best repays the closest study.

625. In addition to some modifications and varieties of real stratification arising from the nature of materials and slight irregularities in the rate of deposition, we often find in certain rocks, especially sandstones of loose texture, a number of laminations in various directions, which not having any relation to the circumstances of deposit are called "false stratification." In figure 128 an example of this is shown; and although there seems to be lamination in several directions, the true direction, if there be any, does not appear. The exact cause of this curious appearance has not been very clearly made out.

Fig. 128.



Appearances of false stratification.

626. It is not to be supposed that strata must all have been originally horizontal, many causes preventing this, especially when accumulations are rapidly advancing on steeply shelving coast lines. The exceptions to the general rule cannot, however, extend very widely, and are not likely to affect important rocks, although this possible cause of unconformable stratification is too real to be neglected. "There are numerous situations off the edges of what are termed soundings, or minor depths of water, on many and extensive lines of coast, where we can imagine the effect of the current but barely sufficient to push grains of sand over a steep bank, thus causing the formation of strata of sand with an inclination of from 15° to 30.° Minor effects of this cause are constantly observable on the shifting banks of rivers, and are to be found, as has been often observed, in almost all sandstone rocks. The formation, therefore, of moderately elevated strata, upon a larger scale, is precisely what we should expect under favourable circumstances." *

627. In now concluding the subject of stratification and the mechanical displacement of strata, it remains only that we remind the student of one important fact—namely, that although it has been regarded as a prevailing rule in nature for a given stratum to consist of one rock, or even of one modification of a rock, yet this rule is far from universal. The commencement of a deposit may be in sand; and in consequence of some change in the direction of marine

* De la Beche's "Researches," p. 52.

or river currents or other causes this may by degrees give place first to loam, and then to sandy marl, until at length a calcareous or argillaceous mud comes in, totally different from the original material; or, which is perhaps more common, a deposit may commence with coarse conglomerate, and by slow and imperceptible gradations this may change to the finest mud. The reverse may also take place; and in either case there may be no possibility of marking the precise spot where the stratum changes. Mere difference in mineral or mechanical condition is not, therefore, of itself enough to distinguish one stratum from another. This change may occur either in successive deposits placed vertically above each other; or laterally, the deposit at one part of a coast line differing from that at another part not far off and at the same level.

628. We have hitherto said nothing of these remarkable appearances infinitely common in some districts, where strata, instead of presenting their usual regularity, are twisted and contorted into the most singularly complex forms. This crumpling up of strata occurs both on a small and large scale, being sometimes confined to a small portion of an exposed cliff, and sometimes extending over a whole country. As conducting towards an explanation of the other mechanical disturbances of rocks, perhaps no phenomenon is so important, but viewed simply in reference to superposition, it resolves itself into a succession of parallel anticlinal and synclinal axes, multiplied many times; and often, in consequence of the folds being partly turned over, presenting long and frequent series of inverted strata.

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629. Amongst the changes that have taken place in rocks must be ranked those whose tendency is to split the rock in certain directions by what are called "joints." These are interesting in many respects as structural phenomena, and in this sense we have already alluded to them. We must also consider them as exhibiting mechanical modifications of rocks, and therefore as part of the subject now under consideration. Joints are defined to be natural fissures, traversing rocks in straight and well-determined lines, and forming planes of separation, which are often slightly open, and which not merely pass through strata, but through various semi-crystalline aggregations, evidently formed since the original accumulation of the strata.

630. Numerous observations, made in various localities, with regard to the direction which these fissures take, have already led to interesting results; and the continued attention of geologists to this subject will probably, in time, become the source from whence many interesting generalizations may be deduced. As an instance of such observations, and of the importance of multiplying them wherever there is opportunity, we may mention that in a very large

majority of cases, the joints in the mountain limestone districts in the north of England, in Derbyshire, and in parts of Ireland, have either a direction varying but little from N.N.W. and S.S.E., or a direction at right angles to that; and out of 89 observations made by Mr. Phillips in Yorkshire, 55 of them exhibited the joints varying between N.W. and S.E., and N. and S.; 28 were at right angles to these; and there were only 6 which deviated to any considerable extent from this apparently general law.

Mr. Darwin mentions that the clay slate, in Navarin Island, Tierra del Fuego, is in many places crossed by parallel smooth joints. Out of five examples the angle of intersection between the strike of these joints and that of the cleavage laminæ was in two cases 45°, and in two others 79°.*

631. Veins also are phenomena which require description here, and which, as they are sometimes undistinguishable from joints; sometimes resemble beds or seams; sometimes are open crevices, whose length, breadth and depth, vary infinitely in different cases; and not unfrequently are irregular fissures crossing each other and the enclosing rock, and crossed by faults, dykes and joints; need careful and somewhat minute definition. The annexed diagram, fig. 129, represents a section of such vein in stratified rocks.

Fig. 129.

Section of a mineral vein.

Veins differ from dykes rather in their contents, than in the form and nature of their bounding walls. Both are fissures in rocks, filled with mineral matter subsequently to the existence of the fissure as an open crack; but when such fissures are filled with trappean, or other igneous rocks, or with felspar in any shape, injected, apparently, in a state of fusion, they are called "dykes (see § 622);" while, when they are associated with metalliferous ores, or contain crystalline minerals, they receive the name of "veins." Veins, therefore, are commonly filled with copper, lead, tin, or other metals, in combination with sulphur, oxygen, carbonic acid, &c. associated with the salts of lime and barytes, and with iron, argillaceous matter, and quartz.

632. Veins have been variously but not very completely or clearly defined by various authors; and the statement of Werner that 'they are mineral repositories of a flat or tabular shape which traverse strata without regard to the stratification, having the appearance of

* Darwin's "South America," p. 155.

rents formed in the rocks, and afterwards filled up by mineral matter, which differs more or less from the rocks themselves,' has been received rather in the absence of one more accurate than because of its really describing the greater number of carefully observed examples. Veins, in fact, are by no means flat or tabular; they often exhibit distinct reference to the stratification of the containing rock; and the mineral matter included, although it certainly differs in almost all cases from that of the surrounding rocks, does so only in a way which marks some common action between the two.

633. If we consider for a moment the causes concerned in producing the mechanical displacement of which it is the object of this chapter to give an idea, it will be evident that while subterranean force resembling that still elevating wide tracts, and producing narrow fissures in rocks of limited extent, is beyond all doubt a very essential one, there must be another even more widely acting, and producing somewhat similar results. The change of volume that takes place when solids are affected by heat cannot fail to act when a large mass, occupying thousands or tens of thousands of square miles, is altered in position by being removed below the stratum of invariable temperature, and thus raised for centuries to a perfectly regular and even temperature somewhat higher than that of the sea-bottom in which it was formed. Nor, on the other hand, can there be a perfect equilibrium maintained among the parts of a similar mass if, after being elaborated and modified by exposure to long continued magneto-electric currents at a uniform temperature, it is at length upheaved above the invariable stratum, reduced in temperature, and exposed to great and very irregular surface action. In the first case there must be a certain amount of expansion, in the latter a corresponding degree of contraction; and while the former cannot fail to exert mechanical compression on adjoining beds, the latter will produce a solution of continuity in the whole mass itself, especially when altered by chemical action and by the partial crystallization it has undergone.

634. It has been determined by experiment that the rate of expansion of various rocks in the direction of their length is as follows, for each degree of Fahrenheit:—

Greenstone	·000004499
Granite	·000004825
Marble	·000005668
Slate	·000005764
Sandstone	·000006524

From this table it is easy to calculate that if a mass of compact sandstone, extending for a hundred miles in length, is, by however slow degrees, removed from the earth's surface to a depth of 10,000 feet below the stratum of invariable temperature, where it would attain a temperature of 180° Fahr. above that of its original position, it must undergo an expansion, the additional length amount-

ing in all to 620 feet; and we may fairly suppose that any compressible strata, irregularly squeezed by this irresistible force, must be affected and contorted in a very marked degree. If on the other hand a granite rock, measuring 100 miles in length, be elevated from a depth of 10,000 feet to the surface, it will undergo a contraction in length, from change of temperature alone, amounting to as much as 460 feet, and this must be chiefly perceptible in widening the prevailing sets of crevices or joints determined originally by crystalline action. The fact of this space, amounting on an average to four and a half feet of crevices per mile, being produced in granite by contraction alone in rising from a depth so inconsiderable, and without exposure to a temperature much higher than that of boiling water, cannot but show the necessity of reconsidering many explanations sometimes given of vein phenomena.

635. In addition to this very important and influential cause of contraction we must also take into account the effect of parting with water, of which stratified rocks near the surface always contain a large quantity, while crystalline rocks and even semi-crystalline limestones and sandstones are comparatively dry. The extent of this as a cause of contraction can hardly be measured, but must probably far exceed in amount the contraction from altered temperature, and it affects all accumulations of whatever kind that can be made at the sea-bottom.

There can be little question that a certain amount of chemical action may result from the gradual separation of water from solid bodies, while a portion of the contained water is also no doubt decomposed during metamorphosis. Coal affords a familiar example of this, since in the ordinary varieties the proportion of water is exceedingly small, while in all kinds of vegetable matter, and even in lignites, it is very large.

636. Veins are by no means confined to granite or slate, or indeed to any particular rocks, since the essential phenomenon—a crevice in a rock more or less completely occupied by some simple minerals or metallic oxides—may be observed in every considerable mineral mass of whatever kind; but there is some advantage in carefully studying the appearances put on in those rocks where the crevices are most distinct and most definitely filled. We therefore quote without hesitation the careful and practical account given of them by Dr. Boase.*

637. "When a section of the primary rocks is closely inspected, it is found that no individual rock continues pure and uniform in its composition for any considerable extent; and far more commonly, each of its constituent blocks, or concretions, exhibits a striped or variegated appearance, on account of numerous irregular veins which intersect its mass. These minute veins are more or less simple in their com-

* Treatise on Primary Geology, p. 167, *et seq.*

position: very frequently they consist, for the most part, of a single mineral, the nature of which generally bears some relation to the constitution of the containing rocks: thus quartz-veins are found in all rocks, which might be expected, since all rocks abound more or less in silica; but they are most frequent in those rocks wherein this earth predominates; so, likewise, calcareous veins occur in rocks into the composition of which lime enters, and veins of Asbestos, Steatite, and other magnesian minerals, characterise Serpentine, Amphotide, and other rocks of a congenerous nature, and, lastly, whatever may be the peculiar and distinguishing mineral of any series of granitic or schistose rocks, whether Hornblende, Chlorite, Schorl, Actinolite, or Mica, small veins and patches of the same substances impart to the mass an appearance more or less variegated. Sometimes, however, the substance of these veins is compound, exhibiting either distinct or homogeneous crystalline mixtures of two or more minerals, which very commonly are only varieties of the rock in which they occur: thus, veins and irregular portions of fine-grained granite, of syenite, of shorl-rock, and of other granitic species, are frequently completely enveloped in various kinds of granite, and hornblende-rock, actinolite-rock, and other members of the schistose group, containing small veins of a more crystalline nature, imbedded in the homogeneous varieties, and *vice versâ;* these occurrences, however, are not very conspicuous, unless rendered obvious by a partial decomposition, by which the harder or more crystalline parts are brought into alto relievo on the surface of the blocks.

"Such is the composition of the small or concretionary veins of the primary rocks: the next points for consideration are, their connection with the rock, and their structure.

638. "A fresh fracture, or, indeed the external surface, if the rock be of a durable nature, shows that the substance of these veins is often intimately blended with that of the rock; so that it is impossible to say where the one begins and the other ends: but this is not always the case, and, indeed, even where one part of a vein appears to be in the former predicament, another part is bounded by a distinct line, on each side of which the substance of the vein and the rock are strongly contrasted.

"So, when the rock has suffered from the decomposing action of the elements, these veins often exhibit perfect walls, or even an open seam or crevice, the chemical change being more rapid at those points where substances of a different nature come into contact; but in those veins, or in those parts of veins, as in the case just mentioned, in which the junction is accompanied by a perfect transition, decomposition does not develope this disunion of parts.

"As to size, length, and other dimensions, these veins exhibit every variety within the limits of the containing block or concretion: as regards their form, they are either straight or tortuous, more or less uniform in breadth throughout their course, or tapering at one or both ends, they terminate in one or many filaments; and, lastly, when they meet in opposite directions, some appear to traverse others, and the disconnected veins either continue in the same lines on both sides of the interposed veins, or in parallel lines, at some distance from each other, on the opposite sides of the latter veins; in short, exhibiting on this small scale all the phenomena which have been observed in the largest veins; and sometimes these characters are distinctly marked even in hand specimens, as in the slate of St. Agnes, and in the granite of Carclaze, in in both of which the minute veins are metalliferous.

639. "Let us now advance a step farther, and we shall find that when these rock concretions are not individually contemplated, but in the aggregate, as united into a layer or bed, the same appearances are still exhibited: larger veins, but similar in composition to those just described, traverse different concretions, not unfrequently penetrating through their very substance, and even intersecting and anastomosing with the lesser concretionary veins; more commonly, however, the larger veins are interposed between the boundaries of the individual concretions of the rock. In the latter case, the veins sometimes unite the blocks into such a firm mass, that they are not separated by the action of the elements; but, in general, these veins by being more crystalline in the middle part, are readily disunited along this partially open line or

chain of drusy cavities: and thus it is, that we so often find one or more sides of weathered rocks coated and protected by the moiety of a vein; in granite, for example, the blocks often exhibit a surface of quartz, and in serpentine, of steatite or asbestos.

"Proceeding still farther, we arrive at the immense masses of rock resulting from the aggregation of the layers and strata: on this large scale, we do not find so great a diversity in the mineral composition of the veins, as in those minute ones, that are confined to the concretions of rocks; but still this is in perfect keeping with the general design, for the minerals which produce these rare concretionary veins, do not enter into the construction of extensive masses of rocks, but are confined to a few and limited localities."

640. Veins are often limited manifestly in length and breadth, and even in depth; but this appearance is sometimes obscure and sometimes deceptive, for a vein dying away for a considerable distance may afterwards reappear at a still greater depth, and there prove highly productive. The distance on the surface amounts in some cases to many miles, but is partly dependent, it would seem, on the general extent of the mineral district. One of the largest veins worked is from 25 to 50 yards in width, and has been proved for a length of 6 miles and a depth of 1000 feet. It is in Mexico. There are great difficulties in tracing veins at the surface, owing to the oxidation and decomposition of the vein-stone and the covering up of vegetable soil.

641. Nothing can be more variable and unaccountable than the relation of the metallic ores in a mineral vein to the circumstances of position of the vein, but in spite of this there exists throughout a certain amount of order, and an approach to regularity. In all districts traversed by mineral veins, there are, for instance, what may be called systems of veins, each system being characterised by some peculiarities of position or contents, and each, so far as we can judge, referable to a distinct period. In Cornwall there have been described eight such systems, and the same number had been observed by Werner at Freyberg.

642. In Cornwall the first class of veins are those which appear to have been the earliest formed, and they form a very large majority of the whole number in the district. They are the older tin veins; they underlie to the north, and are traversed by those of the second class, which are comparatively few in number and of small importance.

These two classes include all the lodes from which tin ore is extracted; their width varies from a mere string to as much as thirty-six feet, and most of those which are productive range east and west.

The third class of Cornish veins are the east and west copper lodes, and these form the greater number of all the copper lodes in the county; they always cut across the tin lodes, when the two kinds meet, and they are usually accompanied by small veins of clay.

The fourth class consist of what are called the *contra* copper lodes, and are few in number; their direction is either north-east and south-east, or at right angles to those bearings.

The fifth class includes the cross-courses which run south and west or nearly so, and contain no tin or copper, though sometimes a little lead ore: their underlie is various;

they are tolerably wide, and have been traced on the surface to considerable distances.

The remaining three classes are of comparatively small importance to the miner, but they are valuable as adding to the number of facts on the subject of mineral veins. One of them includes therecent copper ores, and another the corresponding cross-courses, while the last includes the *slides*, (composed wholly of slimy clay,) consisting of a number of narrow imperfect veins, rapidly underlying, and running in all directions.

In almost every case the productive veins run east and west, and the cross-courses north and south, and the more recently filled fissures and partings are composed almost wholly of clay, so that as a general rule, veins which contain a greater quantity of this clay traverse those which contain a smaller quantity.

643. The systems of veins in the Freyberg districts are described by Werner, and offer a series of facts somewhat analogous to those observed in Cornwall, but the metals are different, and so also are the prevailing directions of the lodes. The first, and most ancient are chiefly north and south, and include those veins from which the chief supplies of lead and silver have been obtained. Those of the second system (*contra-lodes*) are more argentiferous, but much thinner. Their direction is about north-east and south-west.

The veins of the third system are all north and south, and those of the fourth at right angles to them, being what are called in Cornwall cross-courses. They both contain lead glance. The others are less important.

In the English lead districts, the systems of veins are much more simple than in Cornwall or Saxony ; the direction of the productive veins is, almost without exception, east and west, and they are traversed by cross-courses, not productive, at right angles to them. The underlie is seldom considerable, and it is tolerably uniform throughout the district.

644. On the whole, and viewed with reference to the whole district, the direction of the productive veins in Cornwall is strikingly uniform, and the mean of nearly 300 observations, recorded by Mr. Henwood, gives 4° south of west, while the actual direction in nearly two-thirds of the number differs but little from the average.

The actual number of observations tabulated is 295 ; of this number the direction in 182 instances was between west and south-west, and in 62 others between west and north-west. Dividing Cornwall into ten districts, the mean direction of the veins in seven of the districts is much more south of west than the general mean, as the other three districts chiefly contain the contra-lodes.

The volume from which this and some other notes are taken, is entirely filled with an elaborate account, by Mr. Henwood, of the Metalliferous deposits of Cornwall and Devon.*

645. Besides the productive veins or lodes, all mining districts are traversed by other veins usually at right angles to the former or nearly so, but which are rarely metalliferous ; or which, if they are metalliferous, contain some kinds of ore not abundant in the lodes. The principal minerals in these *cross-courses* are quartz and clay, the quartz being usually crystalline. In Cornwall it was found that out of 163 cross-veins, whose directions were taken, the bearings of 118 were between north and north-west.

646. Several important results may be arrived at from a due consideration of the phenomena of the geographical distribution of

* Cornish Geol. Trans. vol. v. p. 250.

mineral veins, and the general appearances presented by them at the surface. In the first place, it would seem that they occur almost invariably in mountain districts, and are more or less immediately connected with disturbances of strata and with great lines of dislocation, or are in the immediate vicinity of igneous rocks. M. Necker, struck by these facts, which are very evident in a large number of cases, has investigated the subject of mineral veins with reference to these three questions,* viz. first, whether there is any unstratified rock near each of the known metalliferous deposits? secondly, whether, if none such appear at the surface, there is any distinct evidence or any high degree of probability that an unstratified rock exists immediately under a metalliferous district, and at no great distance from the surface? and, thirdly, whether there are found any metalliferous deposits entirely unconnected with igneous rocks?

647. The first of these questions may certainly be answered in the affirmative, by reference to a vast number, forming the great majority, of cases of known mineral veins in all parts of the world. The great mining districts in all countries have been shown to be immediately connected with unstratified and crystalline rocks.

In answer to the second question, M. Necker refers to a number of instances in Europe, where mineral veins occur nearly and evidently associated with unstratified rocks, though not actually preceding from or passing into them.

Such is the case, for instance, in the Isle of Elba, where an abundant supply of iron ore is obtained from veins in sedimentary rocks; but the close vicinity of erupted porphyries and other igneous rocks, and their actual appearance at the surface not far from the veins themselves, is sufficient proof of their presence in considerable abundance.

With regard to the third question, the answer is, although not absolutely in the negative, yet sufficiently so to add great strength to any argument that might be deduced from the answers to the former questions.

The quicksilver mines of Idria in Carinthia, and the lead veins in the mountain limestone of Flintshire and the south-west of England, are among these apparent exceptions; but the former occur in a district nearly connected with the great elevations of the chain of the Alps in its continuation eastwards, and the latter are not far from considerable dislocations and disruptions of the carboniferous strata.

648. Besides the important fact, that the presence of mineral veins is almost always accompanied by indications of the action of subterraneous disturbing forces, and often by the actual presence of igneous rocks, we also learn, from a general consideration of the phenomena of veins, that they are, for the most part, uniform in direction in particular districts, and have a very remarkable tendency so to arrange themselves that the line of their direction shall either be north and south, or at right angles to those bearings. In England, more than half the metalliferous veins are east and west; and this is so uniformly the case in many districts, that the east and west veins are commonly denominated right running veins, while those in the other direction are known as "cross-courses."

649. Observing how commonly it happens that mineral veins make their appear-

* Proceedings of Geol. Soc. vol. i. p. 392.

ance in districts characterized by the presence of altered or metamorphic rocks, it might naturally be assumed that they were chiefly confined to strata of ancient date. This appears, however, to be by no means the case, and metallic ores are known to occur in rocks of the secondary and even tertiary periods. And although some generalisations as to the age of metals are not altogether borne out by facts, there still seems to be a certain order of antiquity in their arrangement, for tin has not hitherto been met with in any rocks of modern date, nor have the precious metals been generally obtained from the older veins.

650. Apart from considerations of age, there are other circumstances, dependent apparently upon local influence in the distribution of metals, which are also worthy of notice. The slates for instance, of Cornwall and Devonshire, are of nearly the same geological age as those of North Wales and Cumberland, but the metalliferous ores found in them differ exceedingly, tin abounding chiefly in the southern counties, copper being the staple in the central and some parts of the northern, and lead in other parts of the northern district. It is true, indeed, that copper and lead are found with the tin in Cornwall, and that lead is associated with the copper of North Wales, and Coniston Water Head; but there are indications of preference, if we may so say, which well deserve careful investigation.

It is a fact of considerable interest, that the limits of mining districts are often very decided, and marked by peculiarities in the physical features of the country. In the north of England, the neighbourhood of Cross Fell has been worked with the greatest enterprise; but no instance has occurred (it is stated by Professor Phillips) of a single vein being traced across the great Penine fault to the west. Similar facts have been observed with regard to the Flintshire veins, which occur in the carboniferous limestone, and which in no instance enter the Silurian rocks. In this latter case, as in many others, the older rocks rise on the line of a great axis of disturbance, and seem entirely to cut off the whole of the mining ground.

651. We have been induced to give this somewhat lengthened account of mineral veins and the circumstances under which they occur, from the conviction that the subject is intimately connected with those of structural condition and mechanical displacement which it is the object of the present chapter to illustrate. This relation may not at first be very manifest, on account of the obscurity enveloping the whole subject; but it will be perceived if we duly study the limits and extent of the phenomena, their mutual bearing upon each other when observations made in distant places are compared, and their resemblance to other phenomena—those, namely, of joints in all rocks, and those of cleavage—which are unquestionably structural conditions, and often induced after the original deposit and subsequent elevation of the rocks in which they are recognised.

CHAPTER XIII.

ON THE CLASSIFICATION OF ROCKS GENERALLY, AND ON THE DISTRIBUTION OF ORGANIC REMAINS, AND THEIR VALUE IN DETERMINING THE RELATIVE AGES OF ROCKS.

652. The classification of rock-formations, like that of minerals, is a difficult, but very necessary subject, and requires an appreciation of several facts in the natural history of animals and plants which we have not yet considered. Little difference has indeed existed amongst geologists of late years with regard to the general plan of arrangement, the main points of discussion having had reference to matters of detail, and the packing in of particular beds in an upper or lower series. Some few anomalies of position, and some difficulties in connecting rocks of distant countries, are, however, still felt, and towards the solution of these, the investigations of travellers and descriptive geologists should be directed. It is only by knowing what is already determined concerning the superposition and representation of rocks in our own country, and others adjacent, that we can hope to arrive at conclusions concerning these less manifest relations, and thus the study of the descriptive geology of one district is a useful and necessary preparation for the general science.

Nor is it less important to the engineer or miner to learn the details of structure, superposition, and relative date of rocks in some one district. The differences that exist amongst rocks of the same age; the resemblance between those formed at different times, but under similar circumstances; and the laws of composition, arrangement, and disturbance of the materials accumulated, are only to be learnt in this way, and the application of geological knowledge cannot be made without some familiarity with the habits of nature in the manner here suggested.

653. It is easy to see, that in whatever way we consider the various layers, beds, or strata, manifestly making up the earth's crust in many districts, there must be involved a succession of operations, all requiring time, so that we may speak of mechanical and deposited rocks occupying the lowest position, as oldest in date, except, indeed, when the beds have been actually inverted by mechanical violence, a condition illustrated in a former diagram (fig. 126), and undoubtedly possible, but occurring rarely, and confined to certain limited districts.

Where too the rocks are not only laminated, showing marks of deposition from water, but also contain the remains of animals and vegetables of any kind, we may judge, in some measure, from the

way in which these occur, of the actual rate of deposition. Thus, if a bed of limestone is made up of numerous thin bands, all loaded with fragments of shells, and alternating with layers of perfect shells of gregarious animals, as oysters, accumulated to considerable thickness and occupying the relative position in which they lived, we may be sure that the deposit has been slow and regular, for these animals require a certain time for the growth of a single layer, and a great many years for the accumulation of a thick bed. So it is with masses of vegetable matter, and other collections of organic bodies, while the most striking example of all is seen in the case of coral, which when built up in vast walls, forming mountain masses, must certainly have required long years, and even centuries to form, while the present appearance of such masses as part of the dry land, affords proof of extensive, but slow changes, affecting large areas of the earth's surface.

654. The element of time is therefore involved to a very considerable extent in all geological considerations, and if the formation of the various deposits themselves has been slow, and dependant on many external causes, there is quite as little doubt that the disturbances and subterranean upheavals which have brought them into their present position, have also required much time, and have occurred only at long intervals. But time alone is not the only cause of change, nor is date the only reason for classification. The geologist must observe mineral character, mineral condition, mechanical arrangement, and mechanical position with respect to other rocks and the horizon, if he would arrive at any satisfactory conclusion, or classify rocks properly.

655. We may regard as the fundamental facts on which classification depends, first, relative mechanical position; secondly metamorphosis; and thirdly, groups of prevalent fossils, if any organic remains exist. Subordinate to these, as far as the main outlines of arrangement are concerned, but still of very great importance, may be ranked, mineral composition and characteristic fossils. Before, however, entering on the details of arrangement, it is essential that the student should be acquainted with the nature of fossils, the laws of distribution of organic beings, both in space and time, and the extent and value of the evidence to be obtained by their assistance, in determining questions concerning the relative age of rocks, and the contemporaneity of those occurring in distant or detached districts.

656. Fossils are the actual remains of animals and vegetables, or other certain indications of their existence, found in examining the rocks of which the earth's crust is made up. The time has been in the history of science, when the presence of the shells of marine animals, or the teeth or bones of quadrupeds or fishes in rocks, has been actually denied, despised, or explained away. When, indeed,

the number of recorded examples of such fragments was few, and the places where they were found, distant, this mode of escaping from a great difficulty in natural history, was thought fair and reasonable; but now that almost every limestone, and a large proportion of all sandstones, clays, and gravels, are found to multiply evidence on the subject; when the microscope is daily discovering fresh proof of the former existence of life in every direction; and when no country is without large and remarkable collections of strange and unfamiliar forms of various animals, obtained, not from the species actually living now in the country, but from the soil and rock beneath men's feet; it would be folly to waste time in proving the interest and importance of a subject so brought home to the senses. We may now regard it as an admitted fact, that almost every rock contains some fossils, and it remains only to consider, what are the conditions in which these occur, the kind of animals or vegetables to which they belong, the nature of the group which the species found in certain localities or certain similar rocks may afford, and the circumstances under which the organic beings in question have lived, died, and been preserved for future investigation.

657. The remains of organic beings found fossil, are as follows:—*First*, the actual substances themselves, formed or secreted by the animal or vegetable, and perfectly preserved, or exhibiting no alteration of substance. Of this kind, are some bands of lignite, or embedded forest trees, and the accumulations of fresh-water shells found in certain deposits in lakes or rivers, and such also are the coralline and shelly masses left by marine animals. *Secondly*, the substances similar to the last in their origin, but more decidedly changed; such as coal, many limestones, and other fossiliferous rocks. *Thirdly*, the altered substances obtained from animal and vegetable remains, when the original mass has become more or less changed into some other material, generally silica or carbonate of lime, but occasionally sulphate of lime, or even some of the metallic sulphurets. In a few of these cases, both external and internal form has been retained, and the latter can often be distinctly traced under the microscope, although the nature of the mineral substance has been altered. *Fourthly*, the form of the original organic body, preserved by some natural process of modelling, that has occurred either with regard to the exterior only, as when the cast of the external and internal surface of shells or bones remains, but the shell or bone itself is lost; or with regard to the whole internal structure, the texture of which is preserved, and admits of microscopic determination, although nothing whatever remains of the original substance. *Fifthly*, and lastly, the impressions made during life, by animals long since dead, on soft sands and clay, retained by some accidental circumstances, and subsequently buried under fresh accumulations of mineral matter. Of this nature

are the footprints of animals, worm-casts—such as those seen on the sea-side—and even the impressions of rain-drops fallen on the sand, which, though not indeed organic, still afford interesting facts in the history of deposits, and have been preserved by a similar instrumentation.

658. The remains found in any deposit necessarily have a distinct relation to the circumstances under which the bed was accumulated. Thus, if the bed in question was formed in a lake of fresh-water, the remains will be those of land vegetables, of fresh-water shells, of crustaceans, of fishes, and occasionally of land animals. So a river deposit near the sea will contain fragments of fresh-water, brackish, and marine animals, often mixed confusedly together; a deposit on a coast will yield the shallow-water marine animals, mixed, though rarely, with those of the land and fresh-water; and a deposit in deeper water, or more open sea, will in like manner indicate by the nature of the organic remains, the depth at which it was made, the existence, direction, and even something of the force of marine currents, and other events concerning the history of the period.

659. Besides, however, all these important and interesting facts, others, even more important and more interesting may be discerned by the careful naturalist concerning the circumstances of deposit, when the fossils of a single bed are examined with attention, and compared with similar groups from other beds, or with accumulations of existing species now in the course of formation. Species are always found grouped according to certain laws, and are represented by analogous species at distant places, or at distant periods, so that the fauna and flora of any place, at one time, possess a distinct and recognisable character. Once familiar with this character, the presence of a group of species in a deposit explains to us directly and distinctly the main outlines of the conditions of the sea at the time of its formation, and enables us to comprehend something of the magnitude of the change that has since occurred.

660. The first and most startling fact made known by the study of fossils is, that we now have wide tracts of land, in which all the physical features indicate that this land has long been removed from the action of the sea, has been clothed with vegetation, and has been the habitation of land animals; but yet where the soil and underlying rocks so abound with the remains of marine animals, or of animals requiring different climate and different physical conditions from those at present to be found, as at once to throw us upon the conclusion, that we stand upon the fragments of a former world, that the ocean once covered all that is now dry, and that all those peculiarities of climate on which we depend as characteristic of any district, are but doubtful and imperfect indications. This state of the case is made so clear by the merest cursory investigation of the

organic remains of any district where fossils abound, that no one can enter on the practical study of geology, without perceiving and being affected by it. It is impossible to doubt that changes so vast must either have been accompanied by the general breaking up of the whole frame-work of the globe, or must have involved the lapse of many ages, if effected without sudden and violent convulsions. Evidence of violent convulsions is, however, not only wanting in most cases, but on the contrary, there are unquestionable proofs of the absence of anything of the kind, so that we are bound to accept the only other conclusion, namely, that the change from the condition of things last past to that now observable, was a change involving a long period of time, compared with which existing dates and human history are utterly insignificant.

661. When, however, the deposits near the surface are examined one after another, as those lower in position are brought successively into view, it is almost equally startling to discover that each one presents in the same way its characteristics, in each the organic remains exhibit some marked peculiarities, separating them from those of rocks immediately overlying, and every investigation of a rock points to a history of change rarely less considerable than that seen in passing from the present to the immediate past. New groups of species, often representative of each other, but never identical, reappear with marvellous frequency and inexhaustible variety, and as we pass gradually downwards in the series the more familiar types of organic structure fail altogether, while the new ones introduced are seen to prevail, until these in their turn give place to others still more obscure, and further removed from familiar and determinable species. Except near the surface, and in a few distant and narrow bands of rock, we find no remains of land animals or vegetables; those of fresh-water animals are more common, but still are few in comparison with marine fossils, which at last seem to reign almost uninterruptedly, the lines of distinction shading off, and the higher forms of organization becoming more rare, until at length these also seem to disappear, and give place to shales and schists affording little more indication of organic existence than some obscure and imperfect casts or impressions of shells, sea-weeds, and other bodies, the organic constituents having been separated to form simple minerals; being collected in veins, joints, and cleavage planes; or appearing, as crystals in porphyritic rocks.

662. Thus distributed through a vast multitude of beds, the nature of these fossil bodies, the grouping of the species, and the laws of their distribution, become of infinite importance in determining doubtful questions concerning the superposition of rocks. For the species of one rock, or of one period, have certain relations of affinity which differ from those relations of mere analogy traceable between the spe-

cies of different rocks, or different ages of formation; and thus the true nature of a group being understood, reference may be made to it as an established and undoubted fact. The true knowledge of one group forms a starting point, whence the complicated web of a broken and disturbed series of rocks may be unravelled, and often no other clue than this exists, or is available, for the identification of distant deposits having no general resemblance whatever.

It is no part of the object of this chapter to give a lengthened disquisition on the nature of the evidence to be derived from fossils, but rather to show their use in classifying rocks. As this, however, is nearly connected with the subject of their distribution and extension, the remarks already offered are not out of place, and will assist the student in his estimate of the value to be attributed to this species of evidence.

663. The importance of fossils must not be measured by the state in which such remains of animals, or vegetables, may occur in rocks. They are often imperfect and fragmentary; rarely present the internal structure, except of isolated parts; are frequently much altered in form, as well as material, from their original condition; and when most abundant are sometimes least satisfactory. Still, in the hands of an able naturalist, they are replete with meaning, and suggest conclusions of the highest importance. One small fragment of a bone or tooth will reveal the existence of a race hitherto unsuspected, and throw new light on the history of a whole formation. A shell will mark the identity of a doubtful deposit with one well known; and even minute objects only discernible by the aid of a microscope will, in the hands of a careful observer, pave the way for discoveries of the highest and most general interest.

664. Let us now trace the use of fossils in the classification of rocks. They may be considered to occur in all deposits of mechanical origin, in which subsequent change has not produced complete crystalline structure; for although many uncrystalline and many massive and semicrystalline rocks do not frequently present these indications of former life, the reason is, that they were accumulated where animals and vegetables did not abound, or could not be preserved: not that these bodies did not exist. They occur in groups of species, some generally characteristic of particular deposits in certain districts; others extending into deposits above or below, or into districts remote from that in which they chiefly abound. The group of species in any one bed is different from those in beds above and below, partly owing to differences of mineral and mechanical conditions of deposit, but partly to the gradual change of species as time has elapsed. Beds deposited in seas of moderate depth, of which the bottom was being upheaved or depressed, must have been for that reason inhabited successively by different kinds of animals; fos-

siliferous deposits near a line of coast accumulating rapidly, and those in the open sea more slowly, must have been greatly affected by the range and magnitude of marine currents; while the influence of change in the form of land must have been felt both in the mechanical and organic deposits of the ocean, and at distances many hundreds and even thousands of miles from the seat of change. Throughout the beds thus formed, the organic remains must retain a true affinity and gradual transition when the changes have taken place slowly; but if it has happened that any change was so rapid or complete as to cause the destruction of an entire race, then the replacement, whether from a distance, or by newly created species, must offer a much more marked contrast. We have already in a former chapter (chap. v. § 183), mentioned some important conclusions as to the habits of marine animals, and to these we must now refer as essential to the full comprehension of the subject of fossils.

665. The principal laws concerning the distribution of fossils are these: *First*, A very large proportion of all the species found in the fossil state, are so far different from any now known that they may safely be regarded as extinct. This law applies to animal and vegetable remains of all kinds, in all parts of the world; the exceptional cases—or those in which species now living are found fossil, not reaching to deposits of any very considerable geological date. The same law applies, to a certain extent, even with regard to those larger and more comprehensive divisions called *generic*, since few existing genera range into the older deposits.

666. The second law of distribution of fossils is but an extension of the first, being to the effect that each principal group of deposits contains a distinct group of species of animals and vegetables in a fossil state. Some naturalists have, indeed, gone so far as to assert, that no species of any single formation extends into the adjacent ones; but we are by no means justified in so general a conclusion from the evidence at present before us on the subject. At the most, this view of the complete separation of all formations by a broad line of demarkation, can only be held by those who, arguing in a circle, assume on the one hand, that if species really pass, the formations are not distinct; and on the other hand, that however near may be the resemblance between specimens obtained from two acknowledged formations, they cannot be regarded as of the same species, *because* the formations are different.*

667. The third law is to the effect, that differences existing between extinct and existing species become wider and more marked as the fossils examined are from deposits of more ancient date. In many very important and easily recognised cases, this is most unquestionably true; and it is equally so whether we examine the remains of

* See Pictet's "Paléontologie," vol. i. p. 58.

animals of high or low organisation, or of vegetables: so that it may safely be admitted and followed out to its legitimate conclusions.

668. The fourth law has reference to the dependance of certain forms of organisation on a given distribution of heat, moisture, and light—in other words, on climatal peculiarities. There is no doubt that at the present day many important groups of animals and vegetables do not naturally range beyond the Tropics, and are confined to limited districts in the same latitude. Thus the largest feline carnivora, the lion and the tiger, are found only in the Old World; and of the different species, some inhabit Africa, and others Asia; while in America, the law of distribution is obeyed by the existence of only representative, and not identical or allied species. In our own country, however, we find abundant proof of the naturalisation of foreign species; for few of those most useful to us are indigenous, and in the train of civilised man are seen every where a number of modifications of nature, some extending to an apparent subversion of the ordinary laws of distribution. There is thus an adapting power in various groups; not certainly to the same extent in all, but always very great if taken advantage of according to the peculiarities of each race. So also in the distribution of animals in time when we find the remains of the elephant stretching northwards into Central and Northern Asia many thousand miles north of its present limit, we are not justified in concluding that the whole change is due to an alteration of climate, since a partial modification in that respect, and some adaptation of species not identical with the existing Asiatic form, would afford a sufficient and more reasonable explanation of the apparent difficulty. Still there is no doubt that the general result of the investigation of fossils has been to show a change of climate; and we are bound to assume that our earth has, at former times, either received a larger amount of heat from the sun, or that heat was once distributed more equally by the atmosphere than it is now. Whether those changes in the position and elevation of the land, which have been already referred to, and which must have taken place, are sufficient to account for the modifications of climate, is a question by no means decided, but still offering many points for investigation. It is important to remark, that the changes seem to have been by no means always of the same kind; for during the period immediately preceding that now in progress, there was a much colder climate than at present; although before that, and generally, there is proof of the temperature having been much higher than it now is.

669. A fifth law in the distribution of fossils seems to be, that the species inhabiting the sea or land during the earlier periods of the earth's history, were more widely distributed than those with which we are now acquainted. This may be only a local phenomenon, and limited to those comparatively small areas with which we are geolo-

gically acquainted; or it may be generally true, but caused by a different distribution of the land upon the globe, and by the wider extent of shallow seas; or it may be the result of an altered temperature over the whole surface. Any one of these causes would tend to bring about a like result; and the geologist must be guided in his choice by a careful investigation of other evidence.

670. It has been generally assumed, that not only was there a wider distribution of species during the early periods of the earth's history, and a smaller number of species and less variety of structure presented; but also, that the earlier faunas and floras were of less complex organisation than those of more recent times. Great stress has been laid upon the apparent absence, or great rarity, of the remains of fishes in these beds; and some have even attempted to draw a line of demarcation below which, it is said, no vertebrated animal appears.

It should, however, have been remembered, that negative evidence is in all cases most unsatisfactory, and that in the early development of a science of observation like Geology or Palæontology, there is especial liability to error from hasty generalizations. There can now hardly be a doubt that this rarity of fishes' remains amongst many of the older rocks, is not owing to the absence of these animals from the waters of the wide ocean, but that particular local causes were unfavourable either for their rapid multiplication, or for the preservation of their bones and teeth. Numerous specimens referred to many species and genera, have been already found; and as the localities in which fossils occur in the oldest observed mechanical rocks are multiplied, so will evidence concerning the fishes, and even perhaps the marine reptiles of these districts and times become more common; though it is not at all likely that we should find direct indications of the presence of birds and quadrupeds, even if many groups of the highest order of vertebrata really existed on the land.

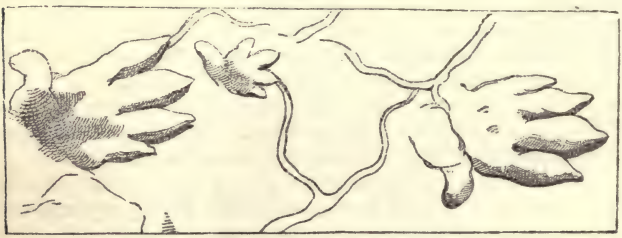
671. The true state of the question with respect to this supposed law (which is sometimes spoken of as a law of development of animal and vegetable structure generally, and as involving an actual advance in organisation in every successive introduction of new species) seems to be as follows: First, That the seas depositing those rocks now referred to the most ancient period, were both more extensive and more shallow than modern seas in the same latitudes. 2nd, That the land then extended in a very different direction, and was less continental. 3rd, That many groups of fishes now common, were then represented by animals allied to the cuttle-fish, and other shell-bearing species. And 4th, that the general distribution of animals in the sea was extremely different from the present distribution, and therefore that we have really but little ground for comparison.

672. We will next consider what sort of organic remains occur in

nature in a fossil state—having already in a former section (§ 298), explained the mineralogical condition in which they are found. They may be divided into three groups : *first*, casts, or other mere indications of the former existence of organic bodies, in which nothing is retained but external form, or the impression made by the solid body on some plastic surface. 2nd, The remains of vegetables, showing actual structure; and 3rd, the remains of animals, consisting either of the shell or other solid frame-work, skeleton, or investment of the animal or any part of it ; or else of the altered substance of the softer part of the creature. Under some one of these heads may be included all possible cases of fossilization or petrifaction ; though in many instances the specimens obtained may seem to partake of the nature of more than one.

673. Under the first class of fossil bodies are included some of great and peculiar interest, and a multitude of others from which very little is to be learnt. Among the former must be regarded the footprints of animals impressed originally on soft mud, and covered up by some new deposit, generally of sand, before they were obliterated. Appearances of this kind are seen in the annexed diagram (fig. 130), and are not uncommon in certain sand rocks where

Fig. 130.



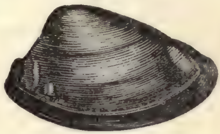
Footprints of an extinct animal
(New Red Sandstone).

thin layers of tenacious marl, alternate with hard and fine sandstone. The cracks produced in the clay by subsequent drying ; the marks of rain fallen at the time of making the foot-prints ; the worm-casts and trails made by crabs, starfishes, and other animals dwelling on the sand, occasionally or periodically washed by the sea ; are all examples of the minuteness with which mere momentary and accidental conditions may be, as it were, stereotyped, and preserved for the contemplation and investigation of distant ages. No one can doubt that such operations are still in progress on our own and other shores ; and thus we have in these footmarks a striking proof of uniformity of general conditions in ancient times ; although in the particular spot where they occur the sea has long ceased to roll over them,

having deposited many hundred, or even thousand, feet of beds left to harden and become rock.

674. An example of the other kind of fossils belonging to this first series is figured in the next diagram (fig. 131), which represents the internal form of a sufficiently common shell found in the beds immediately below the chalk in England and France. In some deposits, especially clays, the carbonate of lime of which the embedded shells were composed is ultimately removed, probably by the slow action of acids, but remains long enough for the shell to become so accurately filled with mud or other foreign material, that when the shell is removed its form is retained. It is often possible from such casts to determine known species; and they are thus not without value, though generally far inferior in this respect to the more perfect casts which exhibit structure, or to the actual substance of any part of the animal or its stony habitation.

Fig. 131.



Cast of Nucula pectinata (Gault).

675. Other kinds of casts are sometimes found; namely, when the interspace between the material filling up a shell, or substituted for organic structure, and the similar material deposited outside, receives a new substance after the original shell is gone. We then have a true representation of the external surface and form, more or less perfect as the material is more or less favourable for receiving impressions: vegetable remains are thus not unfrequently presented for investigation. Lastly, we may mention as among the indications of former organic existence of the nature of casts, the mere hollow spaces in which organic bodies have once existed, but which present now scarcely the form, and nothing of the structure of the original. Indications even so slight as these are not without value in many cases where the object is rather to detect the fact of organic presence, than determine the nature of the embedded fragment. Of this nature are the fucoids, or sea-weeds, in some very ancient schists; and the discoloured patches—the filling up of these empty spaces with foreign substances—not uncommon in still more crystalline rocks. It is, however, often difficult to distinguish between vesicular cavities in altered and crystalline rocks and the spaces once occupied by a shell or other animal substance.

676. Of vegetable remains found in a fossil state, the leaves and the trunks of trees are very general, the hard fruits not unfrequent, and the floral envelope extremely rare. The resinous exudations of pines may also be mentioned as fossils of this kind. An example of the way in which the fronds of ferns are preserved in the rocks associated with the coal beds is given in the annexed diagram (fig. 132); but by far the largest proportion of fossil vegetable matter is so far

altered from its original condition as to have lost the immediate trace of vegetable tissue, and in this state it forms the mineral fuel well known under the name of coal. The traces of leaves are chiefly found in the sandstones and clay-bands or shales, above and below the principal mass of carbonaceous matter, and in addition to them the trunks of trees are by no means rare. An example of one is

Fig. 132.

Pecopteris aquilina
(Coal measures).

Fig. 133.

Sigillaria pachyderma
(Coal measures).

shown in fig. 133, which represents a portion of a remarkable cylindrical-stemmed tree, often attaining a height of 40 or 50 feet, fluted longitudinally, and marked at intervals by scars, where leaves had once been inserted. The great mass of fossils in the coal formation consists of plants to which modern tree ferns bear the greatest resemblance.

677. In addition to the plants from the coal beds and those adjacent, a very large number of species have been found in other rocks and will be referred to hereafter. We append a comparative view of extinct and recent species, as calculated by Prof. Bronn from very recent documents.

	Recent.	Extinct
I. Cellulares, or Acotyledons	9100	188
II. Vasculares,		
A. Monocotyledons, or Endogens	10629	1139
B. Dicotyledons, or Exogens.		
a. Monochlamydeæ	3246	358
b. Corolliflorae	23900	28
c. Choristopetalæ	22528	175
III. Doubtful	..	167
	69403	2055

678. To explain the formation of beds of coal has always been considered a difficult problem amongst geologists. In our own country these beds are exceedingly numerous, but (with only one apparent exception) are of inconsiderable thickness, not often exceeding seven feet, and, in far the greater number of cases, being only a few inches. This is, however, by no means always the case, for the bands of carbonaceous matter called *Lignite*, found in many parts of the continent of Europe and in India, and the coal-beds of America are sometimes of enormous thickness, amounting to fifty or eighty yards in particular spots. As in order to obtain this enormous thickness of coal a corresponding accumulation of vegetable matter was absolutely necessary, it is not easy even to conjecture the circumstances under which the deposit took place. "The remarkable case of an erect fossil, many feet long, having deposited around it as many feet of sandstone, followed by underclay, a bed of coal, shale, and other successive deposits, is, however, a startling proof of the rapidity with which the coal-beds were formed, of the rapid decomposition of those which constituted the coal, in comparison with the coniferous wood, and of the probable composition of that deposit of very soft-tissued plants."*

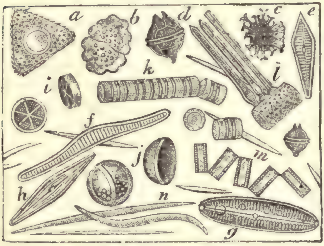
679. Next in order to the vegetable remains, we must mention the silicified sponges and other altered fragments of organic bodies, called by naturalists, *Amorphozoa* (*a* privative, *morphe* form, *zōon* an animal —shapeless animals). These are found in flints and other siliceous aggregations, in limestones, and in sandstones, and occur in rocks of all ages. A very large number of extinct species (461) have been named, but little can be deduced from them, and they may, probably, hereafter, be found to have been separated unnecessarily from known or associated forms. The number of admitted recent species is stated to be only 250, but this, on the other hand, must be below the true number. It is not generally from these very imperfect forms of organisation that satisfactory conclusions can be arrived at regarding the identification of beds. The points of resemblance and diversity are too imperfectly marked, and the causes of change in shape and even in structure of the individual, are too varied to permit of our regarding them as other than imperfect accessories to a knowledge of the age and history of rocks.

680. Amongst the remains of animals found in a fossil state must be enumerated, in the first place, the siliceous (flinty) cases or skeletons of some exceedingly minute and universally distributed species that abound in moist earth, and in fresh and sea water, and which were placed on the extreme verge of animated existence. Some of these, indeed, belong to the vegetable kingdom, and others are only rudimentary forms of somewhat larger races; but their habits are similar, and the greater proportion require the assistance of an excellent microscope even to discover the fact of their existence. Those figured in the annexed diagram (fig. 134) are all enormously magnified in linear dimensions, and it has been calculated by M. Ehrenberg —the naturalist of these minute organized specks of matter—that many of them are not so much as the three-thousandth of an inch

* Dr. Hooker on the Vegetation of the Carboniferous period. Memoirs of the Geological Survey of Great Britain. Vol. ii. pt. 2, p. 410, Note.

in length, and that it would require not less than thirty-five thousand millions of individuals to occupy the space of a single cubic inch. Notwithstanding this scarcely conceivable minuteness, it appears that a very large proportion of the fine earthy powders, into the composition of which silica enters very largely, and which are known as *tripoli, polishing slate*, and *fossil meal*, consists of the siliceous cases which have been secreted by such animals. They are found also in almost infinite abundance in flint and opal, and especially in earthy and opaque parts encasing the solid and translucent interior. At river-mouths, and in estuaries, where tidal action is felt but the surface water is not salt, a vast accumulation of the remains of these animals occurs, for myriads are destroyed by each recurring tide, and every day, therefore, sees a double deposit, which, if not of much thickness on each occasion, becomes at last important. In some parts of the great plain of Northern Germany, deposits more than 60 feet thick of such material have been observed, and near the mouths of the great rivers emptying themselves into the Baltic, large banks of mud and islands, as well as very broad tracts of the coast, are known to be similarly derived. We have already (§ 181) mentioned the general outline of the evidence on this subject, and now it is only necessary to allude to it again to remind the student of the real importance of such kind of remains, on account of the indication they may afford of the circumstances of deposition of the beds with which they are associated.

Fig. 134.



Fossil Infusorial Remains.

a. Desmidium apiculosum.
b. Euastrum verrucosum.
c Xanthidium ramosum.
d. Peridinium pyrophorum.
e. Gomphonema lanceolata.
f. Hemanthidium arcus.
g. Pinnularia dactylus.
h. Navicula viridis.
i. Actynocyclus senarius.
j. Pixidula prisca.
k. Gaillonella distans.
l. Synedra ulna.
m. Bacillaria vulgaris.
n. Sponge spiculæ.

As far as is at present determined, the remains of infusorial and other animalcules are confined to the comparatively modern and upper deposits, and the number determined is stated by Bronn to amount to 672 species, the number of admitted species now living being only 500. This at least is the case with the group called by that author, "Polygastrica," which includes the animals of this kind.

681. The so called *Foraminifera* (see fig. 135—137) are essentially marine shells, and are almost always exceedingly small, but belonged to animals much higher in the scale of organisation than either of the preceding groups. They vary in size from that of minute

points, hardly recognisable by the unassisted eye, to round or oval plates larger than a crown piece. Most of them are, however, between one-twentieth and one-fifth of an inch in diameter; they are divided into chambers, which are arranged on a vertical axis (fig. 135), in a spiral or disc (fig. 136), or in some less simple arrangement, as in fig. 137. As many as 900 species have been described from fossils, and about 1000 recent species are known—the former are chiefly from cretaceous rocks, which in some cases consist almost entirely of them; they range through the whole series of rocks, but are not common in those of ancient date. The shells are in all cases carbonate of lime.

Fig. 135.

Fig. 137.

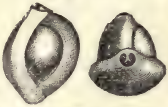
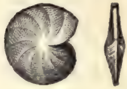


Fig. 136.

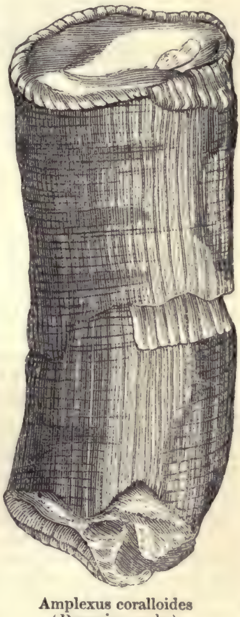


Fossil Remains of Foraminifera.
Fig. 135. Nodosaria limbata.
" 136. Biloculina bulloides.
" 137. Cristellaria rotula.

682. Remains of corals are very common in the limestones of all periods; but the calcareous rocks beneath the coal-measures in England are almost entirely made up of them. The whole number of extinct species is reckoned as high as 2528, against only 1810 recent. The variety, however, is not very great in rocks of the same apparent age, so far as the massive species are concerned; and this also seems to be the law at present.

All the animals of this kind are aquatic and confined to the ocean, and we find them accordingly even in the lower beds, and continued without interruption; the most delicate forms, as *Gorgonia, Flustra, Retepora,* and *Cellepora,* being amongst the earliest of those introduced upon the earth.

Fig. 138.



Amplexus coralloides (Devonian rocks).

683. The species best preserved and most abundant in all countries belong to the larger forms of lithophytes, a tribe now confined to the warmer parts of the ocean. Their skeleton is chiefly composed of carbonate of lime, with a little of the phosphate, and their surface is marked with symmetrical cells for polypi, by which character they are distinguished from poriphera, and by the forms of these cells the species and genera, recent as well as fossil, are chiefly determined. Many genera

are peculiar to the fossil state, but others are still represented. The species figured (fig. 138), is of a somewhat doubtful nature; but it must be regarded as a true coralline body.

The solid remains of Zoophytes abound, as we have stated, in all limestone rocks; and the living species whose enormously extended growth we have had occasion to refer to already, incrust the bottoms and shores of tropical seas, fixing their calcareous secretions on rocks, marine plants, shells, floating timbers, bones, or any solid points of attachment accessible to their ciliated gemmules, swimming through the ocean. They contribute largely to the formation of the rich calcareous soil of many of the South Sea islands, which have passed through the coral-forming strata of the ocean in ascending to their present elevation.*

684. From some analyses of calcareous corals, made by Mr. J. D. Dana, and published in 1846,† it appears that these bodies are usually constructed of from 91 to 96 per cent. of carbonate of lime, with from 2·7 to 8·3 per cent. of organic matter, the remainder consisting of phosphates and fluorides of lime and magnesia, with silica, lime, alumina, and oxide of iron. The following are the analyses of the residuum in four cases, the residuum being taken as unity:—

	Porites favosa, Sandwich Isles.	Madrepora palmata, Antilles.	M. prolifera, Bermudas.	Astræa Orion, Ceylon.
Silica	0·220	0·125	0·103	0·300
Lime	0·130	0·075	0·156	0·175
Magnesia	0·077	0·042	0·385	0·246
Fluoride of lime	0·078	0·263	0·075	0·008
Fluoride of magnesia ..	0·125	0·266	0·026	0·043
Phosphate of magnesia	0·027	0·080	0·002	0·003
Alumina and iron	0·160	0·149	0·253	0·225
Oxide of iron	0·183	....	....	....
	1·000	1·000	1·000	1·000

685. From this table we may conclude that in a belt of coral one hundred miles in length, ten feet broad, and fifty feet deep, there must be nearly 40,000 tons weight of silica, and about five times as much of the various substances mentioned above. It should also be mentioned, that the total quantity of carbonate of lime contained in that space must be estimated at about 20,000,000 of tons—a vast quantity, beyond doubt, but one which, in the course of nature, must be produced in a wonderfully short space of time, when we consider the rate at which coral reefs advance in tropical seas.

It may further illustrate the conditions under which this quantity of matter is obtained if we refer to a former paragraph (§ 44), and calculate the quantity of carbonate of lime present in each hundred miles of sea-water, one mile broad, to a depth of 1000 feet.‡ It will be found to be about 140,000,000 of tons, so that this quantity of salt water would provide seven times the material required for the mass of coralline rock above assumed.

* See a Memoir, by Dr. Grant, on the Characters and Distribution of Extinct Animals, published in "Thomson's British Annual," for 1839, p. 222, *et seq.*

† "American Journal of Science," for March in that year, p. 189.

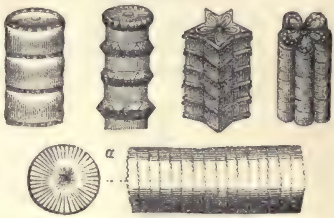
‡ This opportunity may be taken to mention an error of the press in the table referred to (p. 28), where the quantity of chloride of magnesia present in the sea, is stated at 126,720,000,000,000 tons. It should have been 1,267,200,000,000,000.

686. Of the animals which, like our common star-fishes, sea-urchins, and crinoids, are entirely confined to the sea, and present hard, stony, and easily preserved skeletons, a vast number of fossil remains are found in calcareous rocks of all kinds. The total amount of the species is reckoned at nearly 1200, and they are thus distributed :

	Extinct.	Recent.
Stelleridæ (Encrinites, Star-fishes, &c.)	416	286
Echinidæ (Sea-eggs, Sea-urchins, &c.)	770	146
Total Echinodermata	1186	432

The remains of those radiated animals called *Encrinites*, *Crinoids*, or *Stone Lilies*, greatly abound in some of the older limestones ; but the porous spaces formerly occupied by animal tissues, are now usually filled by crystalline calc spar, or even quartz. On the other hand, the more distinct and definite forms—the sea-urchins of the present seas—seem then to have been comparatively rare, but afterwards became much more abundant. The former, the Encrinites, were attached by stems, of which several forms are shown in fig. 139. On the summit of the stems or columns were placed a number of stony plates, forming together a kind of cup ; and from the rim of this cup proceeded a number of smaller columns, serving as hands or arms for laying hold of minute objects floating along in the water Throughout the whole structure an arrangement into five rays or parts proceeding from a centre may generally be traced very distinctly, and is evident in two of the stems figured above. These forms of echinodermata may be regarded as eminently characteristic of the lower beds of limestone, although ranging throughout to some extent.

Fig. 139.



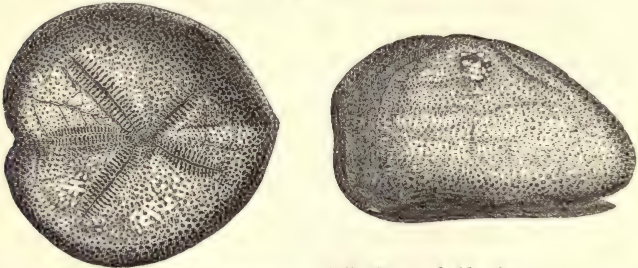
Articulations of Encrinital stems from various rocks.

687. Sea-urchins often possessing singular and interesting points of structure, accompanied by sea-eggs of various kinds, are common in many rocks, and still abound in our own coasts. Figures of one of the species, found frequently in the chalk-beds of England, are given in the annexed diagram (fig. 140), and others will be referred to in future paragraphs. Most of those found fossil are from the beds of oolitic building-stone common in the middle of England. On the continent of Europe, however, the chalk is richer in species than any of the oolites or associated beds.

688. Remains of shells are, as might be expected in marine deposits, exceedingly common, and greatly varied in specific character.

Certain groups now rare were formerly abundant, and others, formerly, it would seem, absent, are now among the most widely distributed. All these, by their different habits and peculiarities, assist

Fig. 140.

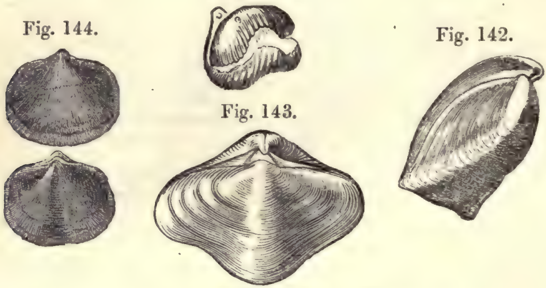


Spatangus cor-anguinum. Chalk. (Top and side view.)

in determining the conditions of the sea in which they were deposited, and each deserves careful attention. Nearly 14,000 extinct species are considered to have been made out.

Of the different groups of shell-bearing animals, one of the most remarkable, and at the same time one of those showing the least complex organisation, is that in which the breathing apparatus, or gills, are appendages to the organs of locomotion of the animal;

Fig. 141. Fig. 144. Fig. 142. Fig. 143.



Group of Brachiopodous shells.
Fig. 141. Terebratula octoplicata (Chalk).
" 142. Terebratula digona (Oolites).
" 143. Spirifer glabra (Carboniferous).
" 144. Orthis orbicularis (Silurian).

ensuring thus by the simplest means an involuntary and perpetual current of water, conveying food within the range of the mouth, and providing at the same time for another, and scarcely less essential function of animal existence, the aëration of the blood. In these shell-defended animals, of which living specimens or shells are rare, but the fossil remains infinitely common, there is seldom a hinge of any kind

connecting the two valves, these being either left entirely unconnected or having a tuft of tendons passing from one shell through an orifice at the peak of the other. This orifice may be recognised in figs. 141, 142, of the group represented above, and the same structure prevails generally. In other cases—and these also are not rare—there is a simple mechanical contrivance of the nature of a spring, whose object is to keep asunder the two valves, and it is interesting to find that in the group now before us, representative forms of which occur in every fossiliferous rock, without exception, in all parts of the world, there are exhibited so many curious, but small varieties of structure, to bring about this comparatively simple and slight result. The characteristic forms of several deposits are seen in the group of figures given above.

689. A remarkable group of animal remains is met with occasionally in rocks at the bottom of the chalk. The species of this group are considered to be the representatives of some rare and ill understood animals, at present inhabiting certain seas. A figure of one species is given (fig. 145), and the group is called "Rudistes." They are characteristic of a particular limestone, chiefly abundant in France and some other parts of Europe (Spain and Portugal chiefly), but extend to corresponding rocks in England. The habit of the animal, and the use of the large shelly habitation it provides for itself, are not well known.

Fig. 145.

Hippurites bi-oculata (Lower Cretaceous).

690. The remains of the more common forms of bivalve shells, those at least most familiar to us in consequence of being brought most frequently under our notice, are on the whole less abundant in a fossil state, though many of them are by no means rare. They are most rare in the lower rocks, and gradually increase in number, approximating at the same time to the form of recent species, as we advance to the examination of beds higher in the series. Thus, in the group annexed the *Megalodon* (fig. 151), although in external form it is not much unlike some existing bivalves, has a very different kind of hinge, seen in fig. 229. The *Gryphea* (fig. 150) is less unlike some existing

oyster-like shells. The *Trigonia* (fig. 147) is truly represented by Australian species of nearly similar form, while the *Astarte*, seen in fig. 148, the oyster, fig. 149, and the *Cardium* or cockle (fig.

Fig. 147.

Fig. 146.

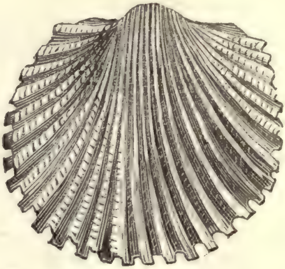


Fig. 148.

Fig. 149.

Fig. 151.

Fig. 150.

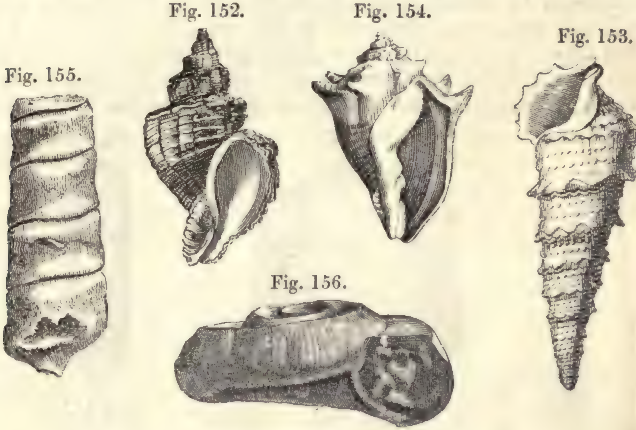
Group of Bivalve shells.

Fig. 146. Cardium porulosum (Calcaire grossière).
" 147. Trigonia alæformis (Lower green sand).
" 148. Astarte elegans (Middle Oolite).
" 149. Ostrea Marshii (Lower Oolite).
" 150. Gryphæa arcuata (Lias).
" 151. Megalodon cucullatus (Devonian).

146), are all so nearly like well-known shells of our own shores, that no difficulty will be felt in identifying them. All those figured are, however, truly extinct species, and most of them have disappeared for ages from the surface of the earth and the waters of the ocean. The gradual approximation of external form and character is but the illustration of an important law, which appears to be of universal application.

691. The great multitude of univalve shells, of which so many varieties are familiar to every one, are likewise repeated in numerous

analogous forms amongst fossil bodies. In the rocks near the upper beds of the series met with in our own and other countries, these are not very dissimilar to the species already familiar by recent and known species, and in the annexed diagram examples of this are seen in the *Murex, Cerithium,* and *Volute* (figs. 152, 153, 154). All



Group of Univalve shells.

Fig. 152. Murex alveolatus (Crag).
" 153. Cerithium mutabile (Calcaire grossière).
" 154. Voluta athleta (London clay.)
" 155. Nerinæa Goodhallii (Coral rag).
" 156. Euomphalus pentangulatus (Carboniferous.)

these might be paralleled, if not from our own shores, at least from shores not very distant; but when we look at the *Nerinœa* (fig. 155), we shall find that, although at first it seems like known species, it really differs much in structure, almost becoming a chambered shell, and indicating an animal with marked and peculiar habits, while in the *Euomphalus* (fig. 156), an inhabitant of much earlier seas, this same peculiarity of structure is even more completely and systematically carried out, although still the external form offers little to remark upon. The gradual change, however, from a shell serving as a partial float, or having great strength combined with comparative lightness, to the earlier form presented in several univalve shells which are simply shelters and defences, and occupied entirely by the animal, is of some interest in the general economy of the Mollusca.

692. The highest group of shell-bearing animals is called *Cephalopoda* (*cephale,* a head, *poda,* feet), and offers a singular contrast, and at the same time a certain analogy in distribution when compared with the Brachiopoda. Like the latter, the Cephalopoda are chiefly found in a fossil state, and range through all deposits, from

the earliest to the latest. Like them also, they are presented in very distinct and characteristic forms in each, and can often be used to identify doubtful strata. The older forms, however, do not depart more widely from the modern varieties than these do from each other; and the genus *Nautilus*, now one of the most rare, except in a comparatively limited range of sea, has its representatives, with scarcely any perceptible difference in structure, in rocks of the most ancient date. Amongst the most striking varieties of form are the straight shells called *Baculites* (fig. 157), common in some parts of the chalk, probably serving entirely as floats; the heavier, but also

Fig. 158.

Fig. 161.

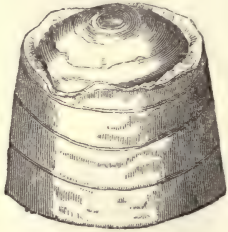
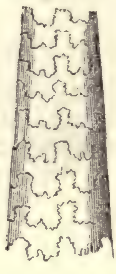


Fig. 160.

Fig. 159.

Fig. 157.



Group of shells of Cephalopoda.

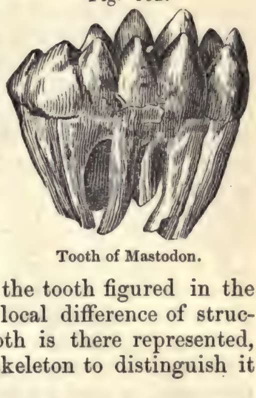
Fig. 157. Baculites Faujasii (Chalk).
" 158. Belemnites mucronatus (Chalk).
" 159. Ammonites Bucklandi (Lias).
" 160. Clymenia linearis (Devonian).
" 161. Orthoceratites conica (Silurian).

straight *Belemnites* (fig. 158), which weighted and steadied certain curious ancient cuttle-fish; the flat spiral *Ammonite* (fig. 159), presented in a rich variety of forms through many long series of beds, the more simple *Clymenia* (fig. 160), approaching the Nautilus, and connecting that genus with the Ammonite; and the singular straight shell called *Orthoceratite*, totally distinct from the Belemnite and Baculite, and removed too far from observation to justify any very decided statements as to its habits and the conditions of its existence.

693. While the seas throughout all time appear thus to have been the habitation of races of shell-bearing animals, gradually departing from one series of forms to exhibit others, sometimes more and sometimes less complex, but never involving radical change, there seem also to have been abundant examples of Crustaceans—the crabs, lobsters, and others now common, being traceable by representative species and genera far back into the earliest records of creation. The insects also, imperfectly as such animals could generally be preserved, offer incontestable evidence, not only of their existence, but of their presence in abundance, and in forms scarcely distinguishable from known recent species ; so that all tribes of animals which could afford evidence of their having once existed by leaving for investigation the fragments of any hard part, or the imprint of the whole body, are seen and proved to have been denizens of our globe, at periods long antecedent to that which comes within the compass of human history.

694. The bones and teeth of fishes, the skeletons of reptiles, and the various indestructible parts of quadrupeds and birds, being also in like manner capable of preservation, have been occasionally preserved in deposits of mud, limestone, and even of sand. The relative proportion is smaller in those rocks which occupy a lower position in the series ; but this alone is hardly sufficient reason for concluding that such animals were rare or did not then exist. When these remains are found they generally indicate marked differences in specific character, if not in genera ; but sometimes, as in the case of the tooth figured in the adjoining cut (fig. 162), there is merely a local difference of structure ; for the elephantoid animal, whose tooth is there represented, had few other peculiarities of the osseous skeleton to distinguish it from the elephant.

Fig. 162.



Tooth of Mastodon.

695. The number of species indicated by organic remains actually observed and described from various formations is exceedingly large, and generally has some relation to the nature of the hard or other indestructible parts. In the case of the Echinodermata, the estimated numbers have been already given, but of the remains of animals of higher organisation, the number of species is very much greater, though still very doubtful. The following table will inform the reader of the conclusions arrived at by Bronn, on this subject, and may be interesting :—

	Extinct.	Recent.
Brachiopoda and Rudistæ	1146	48
Bivalve shells not Brachiopoda	4836	2413
Ordinary univalve shells	6110	8673
Cephalopoda	1546	128
Total SHELL-BEARING ANIMALS	13,638	11,262

	Extinct.	Recent.
Cirrhopoda	87	107
Crustacea Entomostraca	563	143
Do. Malacostraca	244	541
Insects and Arachnidæ	1682	65,600
Total ARTICULATED ANIMALS	2576	66,391
Fishes	1461	8000
Reptiles	384	1055
Birds	148	7000
Mammalia	708	2030
Total VERTEBRATED ANIMALS	2701	18,085

Little dependence can be placed upon these numbers as affording an accurate account of the total number of species either living or extinct, but still the calculation is not without its value, and will, at any rate, serve to show that the subject of extinct species is in the highest degree important. It is also of great value in the geological determination of various rocks, as we shall now endeavour, in a few words, to illustrate.

696. The use of fossils in the classification of rocks we have now shown to be dependent on the universality and permanence of the laws of distribution of organic beings. If, therefore, it were the case that no species passed from one formation to another, and that the same species universally characterized formations of the same date—if even it were true that any perfect and distinct parallelism existed between strata strictly contemporaneous and distinct difference between those certainly formed at distant periods, then might a few well-marked and truly characteristic species save the Geologist much labour in identifying rocks by removing the necessity that now exists of studying, not only the whole sequence of rocks and the possible indications presented by every part of every formation in any one district, but the comparison of these with other recognised types in various parts of the world. Here, however, as elsewhere, there is no royal road to knowledge—no abstract discovery of a species can decide a doubtful question concerning the identity of vast and important deposits; and no mere difference in the abundant and characteristic fossils can be sufficient to justify the conclusion that a supposed contemporaneity does not exist. The whole group of fossils of any deposit carefully examined and compared by a competent naturalist is, indeed, capable of giving positive and distinct information on all the most important questions that can arise concerning the relative date and actual conditions of deposits; but nothing short of this is really important or deserving of any attention. This department of Natural History is, beyond all others, difficult and obscure; and it requires a thorough knowledge of Natural History generally, to justify any conclusions concerning it. Palæontology, therefore, has not for its chief object the amusement of the general reader; nor must the student imagine that the collecting fossils, however interesting and new they may be, induces in the discoverer a power

hitherto unknown or uncultivated, and enables him to examine, compare, and describe these, and refer the bed that contains them to its place in nature.

697. But if there is no blind dependence to be placed on supposed or real identity or diversity of specific character, enabling the Palæontologist at once to decide important questions concerning geological position; neither, on the other hand, can that position be determined solely by investigations concerning superposition, mineral character, or mineral condition. The identification of doubtful rocks in a country whose geographical details and general geological structure are imperfectly known, must be a labour involving many investigations, and much careful comparison of evidence; and is at last subject to some causes of error, until the structure is approximately laid bare. The principles of geological nomenclature include all these points; and a knowledge of all, to some extent, is an essential part of the education of the Geologist. On the other hand, however, it is by no means necessary that the Geologist should be an accomplished naturalist, either in Zoology, Botany, or Mineralogy. He must be a good observer; something of a mathematician and surveyor, to understand the position and phenomena of solid bodies; and he must have a fair acquaintance with the chief phenomena of Natural History. Beyond this every additional knowledge is useful and valuable; but these suffice to commence operations.

698. In the classification of rocks, the use of fossils is so considerable and so manifest, in forming natural groups, and connecting very dissimilar materials by one common and recognisable band of union, that the whole group of rocks are sometimes divided into 'fossiliferous' and 'unfossiliferous.' But this is not practically available in all cases, as many sands and other siliceous rocks have been unfavourable for the preservation of organic bodies. Some clays also are without such indications of their origin, and even some limestones, once entirely composed of organic remains, have now lost this appearance, and are nearly or quite crystalline. We are rather inclined tc onsider each group of strata as marked out by the fossils, when present, but as including even crystalline rocks, when these are manifestly of the same age; and thus we shall avoid a separate class for the imperfectly stratified and metamorphosed rocks, concerning which we have already said almost as much as in this elementary work is desirable.

699. The whole series of fossiliferous stratified rocks may be conveniently divided into three great classes, or principal groups of formations, respectively denominated Palæozoic, Secondary, and Tertiary: these three being sufficiently well marked and distinctive, at least in Europe, to be generally received in Geology.

But in order to understand the value, and even the meaning, of

these and other subdivisions in Geology, they require to be considered with reference to the origin of stratified rocks; and for this purpose, let us assume that the whole series of strata which we find in England, were deposited successively from water, but that, during this long period, many great alterations of level had taken place; the beds being occasionally depressed,—admitting of the deposit of new strata upon them,—and occasionally elevated, and becoming dry land. During the whole period, let us also assume a like gradual and successive change, affecting organised beings both of land and sea. It must be clear that, in such a condition of things, there would be three different states in which the actual solid surface, whether above or under water, might exist: it might be the bottom of the sea, and the recipient of deposits then going on; or it might be also under water, but far removed from the neighbourhood of land, and receiving no additions corresponding to those made under the first supposition; or, lastly, it might form an island or continent, and be exposed to constant denudation, losing a part of what it had formerly received. At another period, the circumstances might be altered; but that portion of solid surface which had existed for a long time without the deposition of new beds, as well as that from which the uppermost surface had been denuded, would necessarily exhibit, in the remains of organised beings found in it, an amount of change corresponding to the period during which there was no additional deposit.

Now, if we consider how large a proportion of the earth there must be at present receiving no new deposits of any kind, and the probability that such a condition must always have existed, and then turn to the contemplation of geological phenomena, we shall cease to wonder at the occasional appearance of breaks in the successive groups; and we shall rather be astonished at the slow and stately progress of the changes that have taken place, and the vastness of the machinery set in motion to produce the effects actually observed in stratified rocks.

700. The nature of geological classification, then, is thus explained: depositions constantly going on, at one point or another, and elevatory movements or depressions of the surface having been equally incessant, there have been, from time to time, such changes produced, either suddenly or gradually, that, in a particular spot, a pause has occurred, and a break in the deposition of strata; so that, when the deposit again commenced, a change had taken place in the nature of the inhabitants of that spot, sufficiently marked to exhibit a distinct character when the fossil remains are carefully examined and compared. From time to time, these pauses have been longer, and larger tracts have been withdrawn from the influence of aqueous deposition for a longer period; so that we are able also to group

together several strata, each stratum being itself more or less distinguishable from the rest. Lastly, there are still more remarkable breaks, distinguished yet more decisively; and these form the fundamental divisions into which all the rest arrange themselves, and to some one of which every stratum may be referred.

701. Viewing Geology in its greatest generality, there is perhaps but one of these latter decided and well-marked lines to be traced throughout the whole series of formations. It is that which separates the strata above the chalk from all that are subjacent: and even this separation cannot be looked upon as a universal phenomenon, although it is so extensive that no instance of real transition of the one series into the other has yet been discovered in Europe, Asia, or America.

Although, however, there is no very clear line of demarcation to be drawn between the different and numerous groups of the rocks of older date, there yet does appear to be one sufficiently remarkable in the change which takes place in the general character of the fossil remains at certain points; and this is a distinction observable throughout Northern Europe, and, probably, also in America.

Taking advantage of this, the whole series of formations, from the chalk downwards, has been separated into two parts; to the lower of which the name of PALÆOZOIC has been applied; the upper beds being called SECONDARY; while the beds above the chalk are distinguished by the term TERTIARY.

702. In the early history of Geology, formations, of whatever period, were called *Primary* or *Secondary*, according as they appeared to be non-fossiliferous, or to contain organic remains. At that time, however, none but the newest members of the series now called Palæozoic were recognized as fossiliferous; and, as the rest were gradually brought into notice, they received the names, *transition, primary fossiliferous, grauwacké*, &c.; names derived from local peculiarities, and involving theories most of which are now given up.

The name *Palæozoic*, indicating merely the fact that the strata so called contain the fossil remains of the earliest formed animals, is now usually employed to designate a comprehensive group; and, from its applicability, and the absence of any allusion to theory, it has come into general use.

703. The further subdivisions of the fossiliferous rocks will be best understood by referring to the following table, in which each formation, or group of strata, is placed in the order in which it is found in nature; and the groups of formations are collected together into systems, and lastly, these systems into the three divisions which have been just explained.*

* "Ansted's Geology," 1st ed., vol. i. p. 88, *et seq.*

TABLE OF CLASSIFICATION OF ROCKS.

TERTIARY EPOCH.

British.	Foreign Equivalents, or Synonyms, and Chief Foreign Localities.
Modern Deposits.	
Raised beaches. Peat bogs. Submerged forests. Deposits in caverns. Shell marls.	Similar appearances in Northern Europe, Siberia, and America.
Newer Tertiary, or *Pliocene series.*	
1. Upper gravel and sand. 2. Till. 3. Mammaliferous crag. 4. Fresh water, sand, and gravel.	These beds, or their equivalents, are known in various parts of Northern Europe and America. Other, but very different deposits, are the newer beds of Sicily. Others, again, are found occupying a large part of South America. Loess of the Rhine.
5. Red crag.	Subappenine beds. Brown coal (of Germany). Belgian tertiaries (Crag). The Sivalik beds (India) are supposed to belong partly to this period.
Middle Tertiary, or *Miocene series.*	
6. Coralline crag.	Touraine and Bordeaux beds. Part of the *Molasse* of Switzerland. Vienna basin. Certain European, Asiatic, North African, and North American beds.
Lower Tertiary, or *Eocene series.*	
7. Fluvio-marine beds. 8. Barton clays. 9. Bagshot and Bracklesham sands. 10. London clay and Bognor beds. 11. Plastic and mottled clays, sands, and shingles.	Paris Basin. Central France. *Molasse* of Switzerland (lower beds). Belgian tertiaries. Various beds in Western Asia and India. Various beds in North and South America. Nummulitic beds.

SECONDARY EPOCH.

British.	Foreign Equivalents, or Synonyms, and Chief Foreign Localities.
Cretaceous system.	
Upper. 12. Upper chalk with flints. 13. Chalk without flints.	*Scaglia* limestones of the Mediterranean. Maestricht beds. *Senonian* division of D'Orbigny (Craie blanche).
14. Lower chalk and chalk marl.	*Turonian* beds of D'Orbigny (Craie tufau). *Quadersandstein* of Germany.

SECONDARY EPOCH (*continued*).

	British.	Foreign.
	Cretaceous system (continued).	
	15. Upper green sand.	*Albian* beds of D'Orbigny.
	16. Gault.	*Plänerkalk* of Germany.
Lower.	17. Lower greensand.	*Neacomian* of Switzerland and France.
	a. Kentish rag.	*Hilsthon* of Germany.
	b. Atherfield clay.	Pondicherry beds.
	? Speeton clay.	Bogota beds, South America.
		? *Aptian* beds of D'Orbigny.
		? *Hils-conglomerat* of Germany.
	Wealden system.	
	18. Weald clay.	Near Boulogne.
	19. Hastings sand.	North of Germany.
	20. Purbeck beds.	
	Oolitic system.	*Jura limestone* is the usual continental synonym of our Oolitic series.
Upper.	21. Portland stone.	Lithographic limestone of Blangy.
	a. Limestones with clay and cherty bands.	Honfleur clays. Solnhofen beds.
	b. Siliceous sand.	Beds in South of Russia and in India.
	22. Kimmeridge beds.	
Middle.	23. Coral rag and calcareous grits.	*Nerinæan limestone.*
	24. Oxford clay.	*Argile de Dives.*
	a. Stiff clay.	
	b. Kelloway's rock.	
Lower.	25. Cornbrash	*Etage Bathonien* is the name given by D'Orbigny to our lower Oolites.
	26. Forest marble.	*Calcaire à polypiers.*
	27. Bradford clay.	*Calcaire de Caen.*
	28. Great Oolite.	
	29. Stonesfield slate.	
	30. Fullers' earth.	
	31. Inferior Oolite.	
	Liassic system.	
	32. Alum shale.	
	33. Marlstone.	
	34. Lower lias.	*Calcaire à gryphites.*
	35. White lias.	
	Upper new red sandstone, or Triassic system.	
	36. Bone bed of Aust cliff.	
	37. Variegated marls, with salt and gypsum.	*Keuper marls*, or *Marnes irisées.*
		Muschelkalk.
	38. Variegated sandstones.	*Bunter Sandstein*, or *Grès bigarré.*

PALÆOZOIC EPOCH.

Magnesian limestone, or Permian system.

39. Magnesian limestone.	*Zechstein.*
40. Dolomitic conglomerate.	*Kupfer-schiefer* and other shales.
41. Lower new red sandstone.	*Rothe-todte-liegende.*

Carboniferous system.

42. Coal-measures.
   - *a.* Gritstones.
   - *b.* True coal-measures.
   - *c.* Freshwater limestone of Burdie house, near Edinburgh.

The coal-measures occupy an important place in various parts of the Continent, in Belgium, France, the Rhine, South Russia, and also in North America, in various parts of Asia, and in Australia. The foreign synonyms are *Steinkohlen-gebirge*, *terrain houillier*, *terrain carbonifère*, and *terrain anthraxifère.*

43. Millstone grit.
   - *a.* Coarse gritstones.
   - *b.* Laminated shales.

The millstone grit is generally a bed of subordinate importance out of the British islands.

44. Carboniferous limestone.
   - *a.* Bands of fossiliferous limestone.
   - *b.* Shales (*Calp*, *Culm*).

The *Kiesel-schiefer* of Germany is an equivalent of the Carboniferous limestone. The Belgian limestone beds, and others in Northern Bavaria, are in the same part of the series.

Devonian, or Old red sandstone system.

45. Quartzoze conglomerates (*Old red sandstone*) in South Wales and Scotland; represented by coarse red flagstones and slates in Devonshire and Cornwall.

46. Cornstone and marl of the old red sandstone. Calcareous slate, limestone, sandy beds, and conglomerates of Devonshire and Cornwall.

Devonian beds are well-known in Belgium, the Eifel, Westphalia, and North Bavaria. In Russia, the Old red sandstone appears, and contains similar fossils to those found both in the corresponding beds in the British Islands, and also in Devonshire and Herefordshire. The palæozoic beds of Australia are supposed to be contemporaneous.

Upper Silurian series.

47. Tilestone.

48. Ludlow group.
   - *a.* Upper Ludlow shales.
   - *b.* Aymestry limestone.
   - *c.* Lower Ludlow shales.

49. Wenlock group.
   - *a.* Wenlock limestone.
   - *b.* Wenlock limestone.

Lower Silurian series.

50. Caradoc sandstone.

51. Llandeilo flags.

Silurian strata extend over much of northernmost Europe, and corresponding latitudes in America. They have been found in Brittany, in Westphalia, near Constantinople, and in Asia-Minor. In South Africa, the southernmost parts of South America, Australia, and China, different contemporaneous rocks have been determined. In mineral character they are generally distinct from the English beds, but offer no marked characters uniformly present.

CHAPTER XIV.

ON THE ROCKS AND FOSSILS OF THE TERTIARY EPOCH.

704. The surface of the earth being everywhere exposed to observation, and necessarily occupying a very large share of attention among those who are interested in agricultural and other pursuits, it is natural, and indeed inevitable, that the geologist should be expected to give information concerning the various deposits at the surface, whether these consist of vegetable soils, barren rock, or the frequent accumulations of fragmentary rocks usually called gravel. These differ exceedingly in actual value and usefulness, and it has become highly important to know whence they are derived, how far they extend, what lies immediately below them, and where these lower beds themselves form part of the surface. All are points worthy of careful study, and many of them admit of satisfactory explanation. In this chapter, however, it will be necessary to confine our attention to the various superficial deposits and the rocks of recent date on which they often repose, considering them only so far as the action of comparatively modern causes can be traced.

705. The beds and other deposits—many of them being by no means regularly bedded or stratified—which occupy the highest place in the geological sequence are divisible into five groups, which we may thus arrange according to the dates of their formation.

1. Recent Period, or *Post Tertiary*. Quaternary
2. Drift Period, or *Pleistocene*.
3. Newer Tertiary Period, or *Pliocene*.
4. Middle Tertiary Period, or *Miocene*. Tertiary
5. Older Tertiary Period, or *Eocene*.

To all these the term *Tertiary* is generally applied in this country, and some of the subdivisions have been named by Sir C. Lyell with reference to the gradual departure from existing species observed in the fossils contained in each. Thus, as in the chalk it was at one time supposed (somewhat incorrectly, as it now appears), that no species of organic remains were identical with species still existing, while in the beds which in England immediately overlie the chalk a small per centage of existing forms was traced, the term *Eocene* was proposed for the latter as being the dawn of existing conditions (*eōs*, the dawn, *cainos*, new). So also *Miocene* (*miōn*, less) indicates that although the proportion of recent species is more considerable than before, it is still less than half; while the appellation *Pliocene*, (*pliōn*, more), marks beds where more than half the species are recent; and *Pleistocene*, a still nearer approximation to the present time. The terms *Post-tertiary* and *Recent*, as applied to raised beaches, recent

marls, and other deposits, surmounting even the newest of the true gravel beds, is not very satisfactory or distinctive, but has been used in the absence of a better. On the continent the word *Quaternary* has been sometimes applied to the newer portion of the tertiary deposits; but this term, although introduced, has not made much way in England, nor does it seem very desirable to complicate the classification by insisting on its use. We now proceed to give a short account of each division of the series as known in various parts of the world.

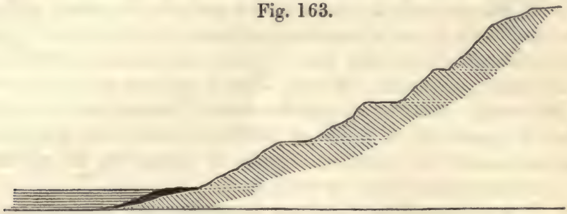
1. *Recent period.*

706. Under this head, rather than that of Post-tertiary, we include all the newest tertiary deposits; but they are presented in forms so different, they have so little connection with each other even in the same country, and they pass so insensibly into the overlying modern vegetable soil and the underlying gravel, sand, or clay of the district, that it is scarcely possible to define their true nature, age, or position. We must, therefore, refer to the principal beds and compare them in the best manner that circumstances will admit.

707. Raised beaches have been already mentioned (§ 237, 238), as occurring in various countries, but especially England and Scandinavia, and as proving great change in the relative level of land and water within a comparatively recent period, and in countries far removed from volcanic agency. It would seem that one axis of these elevations has passed through part of North Wales, where recent shells are found bedded at a height of 1000 feet above the sea, while on either side to the south and north there are no distinct proofs of elevation to so great an extent. From the southern extremity of England to Spitzbergen—a distance of 2000 miles—evidence is obtained at intervals of change of elevation of the beds; and the changes seem to have been rather by alternate periods of elevations and rest than by successive or continuous upheavals. That a very long period must have elapsed during this course of proceeding is, however, clear, from the effect produced on the hard rocks forming great part of the coast line of Scandinavia; and that the periods of repose were very long continued is also certain from the terraces or shelves formed in the cliff, nearly, but not quite, parallel to each other, and repeated successively at several altitudes above the present level of the sea. These shelves often, indeed, present the only permanent marks of the former condition, for though when sea beaches they were covered by shingle, this has frequently been removed since, and the marks of the sea nearly obliterated; and careful observations made upon continuous lines of them have led to very interesting results. On the northern coasts of Scandinavia there appears to be one of these traceable continuously for a long distance, its highest elevation being about 220 feet above the sea,

and gradually lowering to 92 feet. Below this is a lower line at a height from the sea varying from 91 feet to 46, and there are also some intermediate, and some lower terraces not so distinctly marked (see fig. 163). Beyond the tract thus carefully examined, and, indeed,

Fig. 163.



Raised Beaches on the Shores of Scandinavia.

throughout Norway to its southern extremity, there are similar facts presented. In the neighbourhood of Trondjem shells are found on the cliffs upwards of 400 feet above the sea, and the elevation has reached 100 feet higher, the deposit consisting of bluish clays with hydrous earthy oxide of iron. On the shores of the Baltic the elevations are not so considerable, but sometimes even more distinct; and at Uddevalla in Sweden, is a celebrated locality which attracted the attention of Linnæus, and has since been described by other travellers, where several species of shells are found in great abundance in a bed more than 200 feet above the present level of the Baltic, resting on rocks of gneiss, and all the species identical with those now inhabiting the contiguous ocean. Almost everywhere in the northernmost part of the British Islands, but especially in the Shetland Islands and between the main land and western Islands of Scotland, similar marks of recent elevation to an extent of about 250 feet have been clearly traced, while further to the south the elevation increases; and at Moel Trefaen, in North Wales, recent shells are found at the height of 1630 feet above the sea—the highest point yet traced. Towards the south coast of England, where the evidences of raised beaches are also met with, and are sufficiently common, the amount of elevation is not so considerable, ranging generally about 60 feet only, although sometimes more. On the eastern coast of our island the evidence is rather of an opposite kind, indicating a small amount of depression.

708. Besides the raised beaches and other indications of comparatively modern change seen on the coast, the interior of the country as well in England as in Belgium, Germany and France, often presents similar proof in river-valleys, and in the sand and mud filling up caverns in limestone and other rocks. Many of these caverns have been filled up at successive periods, and thus it is difficult to assign any distinct date for them. They will be considered more at length when treating of the next or Drift period.

709. The silt of the valley of the Rhine, known locally by the names *lehm*, or *loess*, consists of a deposit of yellowish marl, often not less than 50 feet thick, and containing numerous calcareous concretions and sandy nodules, forming small groups of hills at the foot of each of the mountain chains which enclose the river valley. Interstratified with it are showers of volcanic ashes, thrown out during the latest eruptions of the now extinct volcanoes of the Eifel and other adjoining districts, and the Rhine has since eaten out a passage, frequently leaving exposed cliffs of considerable magnitude. This bed is sometimes as much as 1500 feet above the sea, and where it terminates near Switzerland is seen to repose on rolled flints and other pebbles of the older, or drift period.

710. It is extremely difficult to determine the contemporaneity of deposits overlying all others, often quite unaccompanied by fossils, and having no relations whatever of mineral composition. Thus it is that the freshwater marls occupying basins of small dimensions on the surface of gravel, are only doubtfully identified with the shelly sands of the recently elevated beaches ; and hence also there is great doubt in the proposed reference of certain large marine deposits, very shallow, and nearly or quite horizontal, to the same comparatively recent period. We are, however, inclined to mention here not only the white marls of the north of the Isle of Man, and many parts of Ireland, and the bog and other peat-moss deposits of the latter country, the east of England, and many parts of North America, but also the *Tchornozem*, or black earth of the Aralo-Caspian plain, the *Regur*, or cotton soil of India, and some portion at least of the deserts of Africa, and the vast terraces of Patagonia. These all exhibit broad tracts, only recently brought into the condition of dry land, and are occupied by deposits which seem too modern to be referred to the gravels and other beds of the same countries, containing many extinct species of animals. The common soil at the surface in most places, containing carbon and available for agricultural purposes, must also be regarded as being comparatively a very recent accumulation of materials.

711. The black earth of the south of Russia extends on the right bank of the Volga from the foot of the Carpathians to the Ural mountains, over a range of country occupying no less than 100,000,000 of acres. It consists of an extremely fertile soil, providing food for upwards of 20,000,000 of inhabitants, and annually exporting upwards of 50,000,000 of bushels of corn of various kinds. It bears successive crops of the same corn for years together without manure, and almost without care. Its thickness is variable, amounting in some places to nearly 20 feet, and it is composed chiefly of silica, with a little alumina and iron oxide, and about 7 per cent. of carbon and other material dissipated by heat, of which no less than

2·45 is nitrogen gas. A very large portion of the remainder of the combustible portion is of vegetable origin. This remarkable deposit covers every other in the district, and is found at very different elevations.

712. The *Regur*, or cotton soil, covers at least one third part of Southern India, and ranges also northwards to a great distance and into the Birman Empire. It is found principally in the elevated plateaux of the Deccan, and in Hydrabad, Nagpoor, and the south of the Mahratta country. It occupies nearly level plains : its colour is bluish-black, greenish or dark grey. It forms into a paste with water, and gives a clayey odour. It absorbs moisture rapidly, and parts with it in dry and hot weather. Its thickness varies from 3 to about 20 feet. It is cultivated very easily, yielding a rotation of crops, consisting of cotton and two kinds of corn. It rarely requires to be left fallow, and demands but little husbandry, although for the last 2000 years this soil has continued in cultivation without manure, retaining the utmost fertility. The following are analyses of the *Tchornozem* and *Regur* respectively, and the reader is referred to a former paragraph (§ 166) for an analysis of the mud of the Nile, which may with advantage be compared with these, as being a river deposit probably very analogous.

	Tchornozem.	Regur.
Silica	75·00	48·20
Alumina	9·09	20·30
Carbonate of lime	*a.*	16·00
Carbonate of magnesia	?	10·20
Oxide of iron	5·56	1·00
Water and organic matter	6·95	4·30
	96·60	100·00

a. The quantity small, but not specified.

713. Very modern deposits analogous to those already described as occurring in the Old World, are found also in America. In the northern division of the latter continent these consist of sand spread over a vast plain in the Texas, and similar deposits in the southern States of Louisiana and Florida. Many of these are freshwater and of modern date ; others are shelly banks recently formed, and sometimes very recently elevated. The southern States and Canada are not without contemporaneous accumulations. The valley of the Mississippi has been subject to undulations within the present century.

714. In South America the newest deposits of Patagonia are of marine origin, and their extent, as described by Mr. Darwin, is enormously great. They extend at intervals (containing generally remains of shells of the same species as those most common in the adjacent seas), from latitude 33° 40′ to 53° 20′ south, or, in other words, for a range of nearly 1400 miles in length, with a breadth of

nearly 400 miles. In some parts the elevation amounts to 400 feet in the southern part, and 100 feet in the northern, and elsewhere it may even be more considerable. The material is here chiefly gravel. Other elevations can be traced for an additional 3000 miles to the north, and throughout the whole range there can be little doubt of the presence of occasional deposits referable to the period we are now considering. No doubt some of these may be of greater age, and may range back into the period of our gravel, but they must partly belong to the most recent period, since they are connected with changes still going on.

715. Australia, although its geology is little known, contains no doubt vast tracts very recently modified, and belonging to the newest geological epoch. The newest beds on the eastern side are sands and gravels, covering raised beaches; and these latter seem traceable at intervals from Van Diemen's Land to the northern extremity of New South Wales, some being from 60 to 90 feet above the sea, and composed of hardened clays, containing remains of oysters and anomias, resembling existing species. New Zealand also, in its accumulations of the fossil bones of an extinct gigantic race of birds, exhibits some proof of recent change, since the gravels in which these bones are contained cannot be of very ancient date.

716. It will naturally be inquired by the student, whether in the investigations made concerning these newest deposits, the remains of man have been found included with those of animals of lower organization, and also whether any cause is discovered by whose agency the various movements of the land can be explained. To these queries we must reply, that the subject is still involved in some doubt. Human remains have been found in a very recently formed limestone rock on the shores of the island of Guadaloupe; and in so far the answer is distinct; but whether they pass beyond the usual limits of what is considered the historic period is not so clear. Some marks of human contrivances, and even some bones of man, have been found in caverns with the bones of animals locally, if not absolutely, extinct, and the marls of the lower part of the period we are now considering have yielded in the British islands fragments of similar kind with the bones of an extinct and gigantic kind of deer. Other similar indications have been found in America, and it would certainly be unsafe to assert, in the face of the evidence that exists, that man has not really been an inhabitant of the earth for a much longer time than historic records seem to show.

717. Neither is there in the deposits we have been considering any proof of the general and rapid destruction of older rocks all over the world; all seems gradual and successive in the history, at least thus far, and if in a few limited districts the accumulations have been diluvial, or affected by the rapid influx of a large volume of water or

a deluge, this is not the case generally. There are no marks of violent transition of any kind universally spread, and the organic remains of the recent period being generally such as would be accumulated under ordinary circumstances at the sea-bottom, now present little to decide the question, so far as fossils of invertebrated animals are concerned. This is not altogether the case indeed with regard to the vertebrated tribes, since in the British islands are found occasionally skeletons of an extinct race of deer, already alluded to. In South America also even the newest beds contain numerous fragments of extinct species of quadrupeds, and in New Zealand the gigantic bird already alluded to, proves that there has been a distinct change in some, at least, of the earth's inhabitants, while the human race was yet in the infancy of its development. We have not space here to introduce any details of this large and important department of Palæontology, and must refer to other works, in which these are to be found.*

2. *Drift period.*

718. So many extensive tracts in England, Northern Europe, Northern Asia, and the two Americas are covered with irregular accumulations of gravel, partly rolled and rounded by the action of water, and such wide tracts are occupied by contemporary deposits, that the consideration of the Drift period, under which name they are here included, has become one of the most important and interesting departments of modern geology. This is the case, not only from the extent and nature of the deposits, but also from the organic remains of extinct races of quadrupeds frequently associated with them.

Under the general term *Drift* we shall find it convenient to include a number of accumulations, which have been thus grouped by Professor E. Forbes.†

1. *Glacial Beds.*—Sands, gravels, and clay marls, often stratified.
2. *Till.*—Unstratified clays and gravels, with boulders, common in the valley of the Clyde, and many other parts of the British Islands.
3. *Mammaliferous or Norwich Crag.*—Fossiliferous sands, shingles, and loam, partly of fresh-water origin.

[The sands and clays of Bridlington are the equivalents of either 2 or 3.]

4. *Fresh-water beds.*—Sands, marls, and gravels.

719. The above subdivisions are useful, not only in the British Isles, but also in many parts of North Europe. The newest of them (No. 1) includes most of the accumulations usually called *Gravel, Erratic blocks, Boulder formation,* and by older geologists *Diluvium;* and to it must be referred the filling up of most of the

* See "The Ancient World," by the author of this work, 2nd ed., 1 vol. 1849. See, also, the author's larger work on "Geology," 2 vols., 8vo. 1844, Pictet's "Paléontologie," 4 vols. 8vo., Paris, 1844, "Mantell's Medals of Creation," and other works on the general subject. Particular treatises are very numerous, and some will be referred to.

† "Johnston's Physical Atlas." Div. C, 9. 10.

caverns. The *Till* is a widely spread and more clayey mass, generally composed of less completely rounded blocks of stone. Parts of it are sometimes called *Boulder clay.* This part of the series extends in the same form over parts of Scandinavia, Russia, Northern Germany and Northern America, and contains fossils rarely. The third, or *Norwich crag*, is a local deposit, and, as well as No. 4, is not found out of England in the same form, although contemporaneous deposits are very extensive in South Europe, Asia, and America. Both the latter beds contain remains of large quadrupeds.

720. The beds No. 1 are called by Professor E. Forbes *Glacial*, because they appear to have been formed in a very cold or even icy sea, subject constantly to the presence of large bergs and fields of drifting ice. The existing land flora and marine fauna of many parts of Northern Europe, and especially of the northern parts of the British Islands, add to the large body of evidence that exists in favour of this view; but we would by no means be understood to support the idea, that any considerable amount of ice then existed as glaciers covering the land in our temperate latitudes, believing rather that much of what is now land was then beneath the waves of the sea, and often served to detain floating ice-bergs, and receive their load of mud and transported blocks of stone.

721. The drift of the British islands may be described as consisting generally of rolled, water-worn, and transported fragments of hard rock, varying in size from many cubic yards to the smallest pebble, but collected with some degree of regularity, and on the whole more stratified in the upper than the lower part. Towards the base the blocks are less regular and uniform in size, and often less rounded by attrition than in the upper beds, and are associated with more stiff clay, insomuch that the latter sometimes almost replaces the transported blocks or boulders, and forms a mass of tenacious clay interstratified very imperfectly with sand. The rocks on which these materials are heaped often show marks of strong mechanical action, having been rubbed smooth and almost polished, or else grooved, striated, and scratched, frequently in parallel lines, and nearly in the same direction over large areas. The material drifted varies greatly, sometimes consisting almost entirely of rocks that have been conveyed from a great distance, and over broad tracts of deep sea, but occasionally and not unfrequently derived either from rocks still in situ, or from others lately removed by denudation from the vicinity of the deposit. Thus the common gravel in many parts of the South-west of England is composed of rolled flints from the beds of chalk which once existed in the immediate vicinity; but in the middle and East of England the material is either granite and other crystalline rock from the Cumberland mountains; or consists of

fragments of limestone and sandstone, or even of clay, from adjacent and only partly denuded beds.

722. It would occupy far too much space if we were here only to enumerate all the localities in which drift beds exhibiting some peculiarities of aspect or condition, are to be found within the compass of England. So varied are the appearances presented, and so numerous the local appellations given, that volumes have been written on the subject, and the deductions are not less interesting than the range of facts is extensive. In the south of Scotland and in Ireland the phenomena are usually more developed than in England, and the variety of deposits greater; most of them, however, consisting of sands, clays, and gravels of peculiar kind, unlike the more regularly bedded rocks. The total thickness is sometimes as much as 300 feet, and the deposit is often nearly 700 feet above the level of the sea. In Scandinavia, and especially in Denmark, the general character of the drift is nearly the same, except that the materials seem to have been not so far transported, and in this respect they may be considered to approximate in character the flint gravels of the neighbourhood of London, but still more resemble the superficial deposits accumulated throughout Northern Germany.

723. The transported drift of Northern Europe may be regarded as a continuous stream of fragmentary material, radiating from Scandinavia and other mountainous countries near the Arctic Circle, and only broken at intervals by natural interruptions. The materials gradually become less in amount, of smaller dimensions, and more distinct from the local rocks, as they recede from the northern mountain tracts, and the source is less manifest at the more distant points. It is, therefore, in Sweden and the islands of the Baltic that the most characteristic forms of the heaps are to be found; and there we see hills of elongated form, called *osar*, ranging from north to south, often consisting only of coarse gravel, and occasionally rising to 100

Fig. 164.

View of an Os, or gravel hill.

or 200 feet above the lower country. One of these is represented in fig. 164, and in most of them the surface is covered with large angular blocks, which appear to have proceeded from the N.W. or N.N.W. Near their origin these blocks are of gigantic magnitude, several having been described, each of which must contain many thousand cubic feet, and one having a circumference of 140 feet and a height of 30 feet. The greater part of the gravel of these hills is of small

dimensions, and mixed with much sand, and they almost always exhibit a slope and a scarped side; the former being towards the north, which is the source of the detritus.

The striation and polishing of the rocks over which the northern drift has passed, is a phenomenon which has attracted much attention, and which is very similar to the appearance presented in the Alps of Switzerland, where glaciers have moved along, down the valleys of that country. The striation is generally in the direction of distribution of the gravel, and varies in different places, no doubt in consequence of the local deviation of marine currents.

724. The whole district thus covered at intervals by the northern drift extends across Europe from the western Islands of Scotland to the flanks of the Ural mountains, and from the mountains of Scandinavia to Central Germany and Poland. The spherical triangle thus formed will be found to contain not less than 2,000,000 of square miles: the number of blocks diminishing towards the extremity, but not regularly, being interrupted by such natural obstacles as the mountain ranges of the Hartz, of Saxony, and of Silesia, and heaps generally including, together with the transported blocks, a large quantity of material torn up from the rocks of the country.

725. A wide distribution of flints from the chalk once covering that part of the country has been traced, not only in the south-east of England, but through many parts of France and Belgium. With these there is rarely any admixture whatever of older rocks, irony sand only being associated with the rounded flints, and the deposits do not often present any considerable thickness. Further south the uppermost beds, though probably of the same date as these, do not put on the same character and cannot be properly described by the term drift. Chalk flints have been found on the coast of Scotland in Aberdeenshire.

726. The diluvial gravels which extend so widely in Northern Europe are met at the foot of the Ural mountains by remarkable auriferous alluvial deposits, whence have been obtained, for many years, considerable supplies of gold. On the eastern flanks of the same mountain chain, the auriferous deposits are even more remarkable for the abundance of their gold produce than on the western, but no true drift including erratic blocks seems to exist between these alluvia and the Altai mountains. In the northern part of Siberia, however, and on the shores of the Arctic Ocean there are extensive deposits, chiefly of frozen gravel, containing the bones and sometimes the carcases of large land animals which must belong to nearly the same date. These extend very far east, and terminate only on the shores of the Pacific. In addition to these accumulations in the northern division of the continent, true gravel and erratic blocks have been found on the summits of the loftiest elevations, near

Macao, in China. They are chiefly of granite, and of enormous dimensions, but it seems questionable whether they can be regarded as continuous through any extensive district.

727. North America presents a formation of transported drift strictly analogous with that of Northern Europe. There are the same heaps of angular rocks brought from a distance, associated with finer sand, rolled fragments, and clays—they are traced in the same way from the north through 1500 miles of latitude, and nearly across the continent, and the gravel hills consist partly of material brought from a distance, partly of rocks torn up from the immediate vicinity. The underlying rocks are also striated, and furrowed, and even polished, in a very similar manner. The accumulation is described as being of loosely aggregated materials, consisting of sand, clay, gravel, and boulders of all dimensions, very irregularly mixed and imperfectly marked with local stratification, as if by the action of violent currents. These materials all proceed from rocks situated to the north-west, from which they are now separated by plains, valleys, and even high mountains, and there is no appearance of their having radiated from any determinable central points. The southern limit of the continuous deposit is a line drawn from Long Island through the north of Pennsylvania to the Ohio, but outliers of similar gravel are found in the valleys of the Delaware, the Susquehannah, and the Mississippi, and very far to the south.*

728. The gravel deposits in South America consist of accumulations somewhat similar to the drift of the Northern Hemisphere, but extending much more continuously and over even a wider range. These have been already referred to; but beneath them there appears a series of beds, also of vast extent, consisting, for the most part, of argillaceous earth, passing into a compact marly rock, and containing numerous fossils, some of them being infusorial animalcules, and others belonging to the most gigantic quadrupeds that have yet been discovered to have existed on the earth. These have been observed over an area at least equal to that of France, and probably twice or thrice as great, and are everywhere of great thickness, and quite unbroken.

729. As containing one of the more remarkable of the contemporary deposits of this period, we must now refer to India, where the local accumulation known as *Kunkur*, and very widely spread over the peninsula, seems to correspond pretty well with the drift of Europe. It is compact, often nodular or tufaceous, and frequently small concretionary, of light brown, reddish, or ash grey colour, and rarely fossiliferous. In its composition it is chiefly calcareous, contaning about 72 per cent. carbonate of lime, and 15 per cent. of silica, with 18 per cent. alumina. It spreads over a very large proportion of

* Histoire des Progrès de la Géologie, vol. ii. p. 373.

India and the adjoining countries, being more especially abundant in the line of country running up from Gujerat to the north-east, towards Delhi. It is constantly observed, not only occupying the low ground, but reposing under the vegetable soil of the elevated plains and plateaux of Central India, and even on the summits of hills between two and three thousand feet above the level of the sea. The Kunkur is not generally stratified.

730. We must now return to Europe, and say a few words concerning the caverns already frequently alluded to, and the fossiliferous deposits occasionally found below the boulder formation. The filling up of these caverns was probably not the work of any one period but spread over a considerable time; but still the greater part of the animal remains point to the drift period as that during which the principal change of this kind took place. The material in the caverns is usually loam and river silt, but is not unmixed with angular blocks, and in many cases seems to have been accumulated at long intervals. The bones found are chiefly those of races of bears and hyænas which had inhabited the caves, but include also the remains of their prey, and fragments of other animals such as ruminating animals, elephants, and rhinoceroses,—probably drifted in. The flints and other boulders introduced are sometimes, though very rarely, accompanied by human remains, but not unfrequently by remains of species of animals still common in the country. These caverns are usually in limestone rocks.

731. Caverns, partly filled with marl, and containing the remains of the former inhabitants of the country, among whom must be reckoned a race of human beings unlike the existing tribes, have been found and examined in Brazil, and seem to be contemporaneous with the deposit of the Pampas beds. As many as 101 species referred to no less than 50 genera of mammals have been described by various authors, but chiefly by Messrs. Lund and Claussen, and almost all these are distinct from the animals now inhabiting the country. Australia, also, has yielded an extinct fauna under very similar circumstances, and in each case the animals which have disappeared exhibit gigantic ante-types of the existing natural families.

732. The fresh-water marls, sands, and gravels, found at the mouth of the Thames, the Stour, and the Medway, and in parts of Suffolk, belong to the older part of the drift period, having preceded the gravel of the country; and the mammaliferous or Norwich Crag, also of the same part of the period, is chiefly composed of shelly beds of sand and loam, well exhibited in the neighbourhood of Norwich, and also at Southwold, in Suffolk. This formation appears to have taken place at the mouth of a river, as many as twenty species of land and fresh-water shells, together with numerous mammalian remains, being distributed through it. Mr. Charlesworth has

named this the *Mammaliferous Crag*, and it well deserves the name, as presenting numerous mammalian remains embedded in a regular stratum. It is also called the *Norwich Crag*. In Yorkshire, near Bridlington, there are certain deposits of sand and clay containing marine shells, of which thirty or forty species have been determined, and most of them are identical with Norwich Crag fossils.

733. Concerning the fossils of the Drift period we have already repeatedly had occasion to mention the abundance of mammalian remains in various cavern and gravel deposits. The most remarkable of these are the large pachydermal species, and some large ruminants, whose bones are common in Western Europe and England, and of which complete carcases have been found in Siberia. The gigantic extinct quadrupeds of South America and Australia, and the birds of New Zealand, speak to the same fact. Of the true drift species of the Northern Hemisphere, we may name the *Mammoth*, or fossil Elephant; the *Mastodon*, nearly allied to the Elephant, and chiefly a North American representative form, though extending also over Northern Europe; two extinct *Rhinoceroses;* extinct species of *Hippopotamus;* several large ruminants among which the *Urus* is the most interesting; a gigantic bear; some large feline animals, and a gigantic Hyæna; a gigantic species representing the Beaver *(Trogontherium)*; and some Whales. In South America, the *Megatherium* and *Mylodon*, and several other gigantic terrestrial Sloths; several *Glyptodons*, or gigantic Armadillos, and some large Monkeys, accompany a multitude of better known and more common forms, while in Australia, the ancient species were also gigantic representatives of the existing marsupial races, now seen in the Kangaroos, Wombats, and other abundant tribes.

734. The remains of Fishes are not common in any deposits of the Drift period. With regard to the Mollusca, we append the following remarks by Professor E. Forbes:—"The fossils found in the British marine pleistocene, are chiefly remains of Mollusca. They are all either living British species now chiefly found within the Celtic region; or such as, though still living within our area, are only abundant in the Boreal region; or such as are extinct in our seas, but still survive in the Arctic regions, or on the coasts of Boreal America. A few southern forms which do not now range to our seas, accompany them. The fauna of the glacial beds, including the Mammaliferous crag, consists of above 170 species of marine animals, chiefly Mollusca."*

3. *Newer Tertiary Period.*

735. Almost the only representative of this period in England is to be found on the coast of Suffolk, and adjacent tracts in Norfolk

* Physical Atlas, *ante cit.*

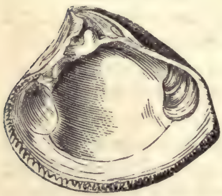
and Essex in a deep ferruginous coloured gravel rarely more than 40 feet in thickness, and generally much less, abounding in fossil shells, and presenting everywhere the appearance of having been formed in a very disturbed sea. This bed is called by English geologists the Red Crag, and we learn from Professor E. Forbes that "there have been found in it about 260 species of Testacea, of which 60 are now known alive in the British seas; 41 of the number are Pleistocene as well, and 19 of the 41 are species common to the coasts of Europe and America. Zoophytes are few." *

736. This deposit is best represented on the continent of Europe by the extensive beds known as the "Sub-apennine" deposits, which are amply developed along the whole extent of Italy on both flanks of the Apennines. They consist of marls containing calcareous matter, and alternating with, or overlaid by sands. They attain a very considerable thickness (said to amount near Parma to near 2000 feet), and offer in some places very marked peculiarities of structure. They contain also numerous fossils, chiefly the remains of mollusca, and the group annexed, figs. 165—167, are common in our own crag, as well as the Sub-apennine beds of Italy.

Fig. 166.

Fig. 165.

Fig. 167.



Group of Newer Tertiary Shells.
Fig. 165. Voluta Lamberti.
„ 166. Murex alveolatus.
„ 167. Astarte Basteroti.

737. Besides the Sub-apennine beds, others of the same period are developed in Sicily and the neighbouring islands nearly to the same extent, and also consisting of marls and occasional limestones. The latter, however, sometimes preponderate, and under the name of *the great limestone*, occupy an important part of Sicily.

Many parts of the eastern Mediterranean, including Greece and Asia Minor, present other beds of this period, and they all generally contain a considerable number of fossil remains, scarcely varying from those of existing seas.

738. The remarkable beds of vegetable matter known under the

* Physical Atlas, *ante cit.*

name of *lignite* or *Brown coal* in various parts of Germany, appear to belong to this part of the series, and require some account, if only from the enormous extent of vegetable matter they contain.

The base of the brown-coal formation seems to consist generally of loose siliceous sand, sometimes passing into a sandstone and sometimes into a conglomerate, and usually containing a thin leafy bituminous lignite called Paper-coal, and fragments of silicified wood, often changed into chalcedony, and occasionally into semi-opal.

The laminæ of paper-coal are associated with thin, earthy, and friable siliceous plates, not unlike the *polir-schiefer*, or polishing slate of other parts of Germany.

739. Beds of clay of various kinds, containing some that are valuable for the potter, and others used in pipe-making, often succeed these siliceous beds, and form the actual base of the lignites. In many places the clay is itself mixed with earthy carbonaceous matter, and in many others it is extremely pyritous.* The lignite which is accumulated upon these clays is of various kinds, a considerable part of it consisting of solid wood, showing little change in specimens taken out of the mine and dried, but bedded in a manner precisely similar to coal, and of a deep black colour. It contains a somewhat large per centage of earthy matter, and although burning with a bright flame, is incapable of standing a blast, and has been hitherto little used for economical purposes. As might have been expected, the different beds of vegetable matter exhibit great differences in this respect, and the fibrous texture of the wood is often so little changed as to admit of portions being actually used as timber in the mines, while, in other cases, the interior is converted into carbonate of iron, or the substance of the wood replaced by a coarse quartzose sand.

740. The lignite is also remarkable for the fossils associated with it, and these consist of the remains of insects, mollusca, fishes, Batrachian reptiles, and even quadrupeds. They are usually in bad condition, and occur chiefly in the paper-coal. It is not uncommon to find the lignite resting immediately on masses of tabular basalt, (near Hachenburg, in the upper part of the valley of the Nister, this is more particularly the case), and it frequently occupies considerable elevations, being found on the top of the higher districts of that table-land which extends over the northern parts of the Duchy of Nassau towards the Vogelgebirge.

741. Belonging to a period nearly the same as that during which the brown-coal was being deposited, we must next notice a remarkable lacustrine deposit of highly fossiliferous marls and limestone, occupying a hollow in the molasse near Œningen, where the Rhine

* At Friesdorf, on the left bank, and at several places on the right bank of the Rhine, this pyritous clay has been used extensively in the manufacture of alum. Crystals of gypsum are often found between the layers of alum slate, and clay ironstone is also common, a thickness of nine feet and a half having been found in thirteen layers, near Rott.

issues from the Lake of Constance. The lower beds in this spot consist of cream-coloured marlstones, containing the remains of plants (chiefly dicotyledonous), of fishes, and of the shells of fresh-water animals. These are overlaid by several bands of fetid marlstone and limestone, all of them exceedingly fossiliferous, and attaining a considerable thickness. In one of the limestones there was found the nearly perfect skeleton of a fox, little different in specific character from the recent fox; and the same quarries have also yielded fishes of large size, a turtle three feet in length, and numerous crustaceans and insects perfectly preserved.

It is clear that this formation must be comparatively recent, but the horizontal beds of which it is composed present escarpments several hundred feet above the Rhine, without any barrier between them and the river.

742. The Pliocene strata occupy a very extensive region in Southern Russia, and are well exhibited in the cliffs on the sea of Azof, where beds of white and yellow limestone contain several species of Cardium and Buccinum and large Mactræ, all of marine origin. Overlying these, and often reposing on intermediate sands and siliceous grits, there also occurs a widely spread limestone, in which are many remains of mollusca that must have lived in brackish seas; and these beds are considered to be an extension of similar shelly deposits in the Crimea and the neighbourhood of Odessa, described by M. de Verneuil.*

743. Deposits of the Newer Tertiary period are met with in various parts of Central and Southern Asia, but they can hardly be separated from those a little older, as they appear to have been deposited in a continuous and quite unbroken series from the commencement to the close of a long period. We shall, therefore, refer to them again when speaking of the earlier beds.

In North America there are many true representatives of this part of the Tertiary period, some of which are very fossiliferous; none of them, however, exhibit any points of special interest.

4. *Middle Tertiary Period.*

744. In the British Islands the representation of this period is very imperfect, consisting only of a few marine calcareous sands, limestone bands, and greenish marl, developed on the coast of Suffolk and Norfolk, in comparatively thin and unimportant deposits. The valleys of the Loire and Garonne in France, the basin of Vienna, many beds on the shores of the Mediterranean, both in Europe and Africa, and others rather more important in Asia Minor and North America, complete the list of those having anything of a similar character. Others, contemporaneous, but altogether dissimilar, form part of the series

* See "Trans. Geol. Soc. of France," vol. iii. p. 1.

on the flanks of the Himalaya in North India, and also of the great range of the South American Tertiaries.

745. The *Coralline Crag* is of limited extent, ranging over an area about twenty miles in length, and three or four in breadth, between the rivers Alde and Stour. It varies in mineral composition, being sometimes entirely made up of fragments of shells and zoophytes, but occasionally, as at Tattingstone in Suffolk, consisting of a greenish marl with a few stony beds, sometimes even quarried as a building stone. The total thickness of the bed rarely amounts to twenty feet, although in some particular localities (as at Sudbury, near Orford) it is much thicker.

746. The fossils most abundant and characteristic of this lower or coralline crag are chiefly the remains of zoophytes, referable, for the most part, to species unknown in a living state. These are incredibly abundant, and are found associated with fragments of echinodermata and shells, one of which is represented in the annexed cut (fig. 168). Above 340 species of Mollusca have been collected in it, of which 73 are living British species, and of these 23 occur also in the beds of newer date. The general character of the marine fauna is described by Professor E. Forbes as Lusitanian; but the zoophytes

Fig. 168.

Rostellaria (Aporrhais) pes-pelicani (Middle Tertiary).

Fig. 169.

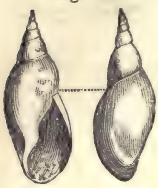
Lower Jaw of Dinotherium (Middle Tertiary).

include many southern genera. Not many remains of quadrupeds are of this date in England; but in the continental beds, especially on the Rhine, near Darmstadt, and in the small valleys of the Jura there have been found fragments of a very remarkable and gigantic pachyderm, having a large and powerful tusk in the lower jaw. A sketch of this lower jaw is given in the annexed cut (fig. 169), and a view of the tooth of the mastodon, also of this period, has been given in a former paragraph (see § 162). Occasionally, indeed, the remains of quadrupeds have been found in greater abundance.

747. The basins of the Loire and the Garonne, and the neighbourhood of Montpellier, are the principal districts in France where the beds of this period are to be found. The beds of the former (the basin of the Loire) are chiefly developed near the city of Tours, and in the "Touraine" district, where they consist for the most part of broken shells, and greatly resemble the shelly portion of the British "Crag." They sometimes, however, form a building stone, the comminuted shells being mixed with sand and gravel, and cemented by the infiltration of calcareous matter. The remains of quadrupeds are occasionally found associated with the shells. The superposition of these Miocene strata upon the lower and older Tertiary deposits, is fully made out in the Cotentin, and elsewhere.

748. A considerable tract of country, extending from the mouth of the river Garonne towards the south-east, is covered up with Tertiary deposits of this middle period, which have been principally studied in the environs of Bordeaux, Dax, and one or two other towns. The beds consist of incoherent quartzose sand mixed with calcareous matter, and they contain a great number of fluviatile shells associated with others of marine origin. As in the basin of the Loire, these fossiliferous beds rest upon strata of older date, from which they are separated by the interposition of a considerable mass of fresh-water limestone. From the basin of the Garonne there would appear to exist a series of Miocene Tertiary beds, traceable at intervals as far as Montpellier, and there overlaid by other beds of newer date, which pass upwards into the older Pliocene deposits.

Fig. 170.



Limnea longiscata (Middle Tertiary.)

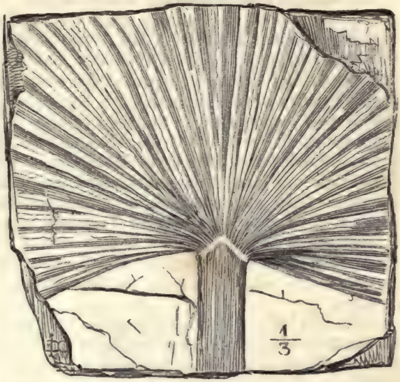
749. In the neighbourhood of Paris there are some extensive deposits of sand, covered with fresh-water beds, which must be regarded as Middle Tertiary, and which contain abundant remains of shells, such as *Limnea* (fig. 170), *Planorbis*, and others with the seeds of *Chara*. These are repeated in a variety of places. The sands are known as the "grès de Fontainebleau," and the upper beds include clays, millstones, and limestones.

750. On the southern flanks of the Alps, near Turin, there appears to be unquestionable evidence that a greenish sand, immediately in contact with the older rocks, belongs to the middle rather than to any newer Tertiary deposit.

751. The deposit called *molasse*, occasionally alternating with beds of lignite, but generally composed of loose sand, is very abundant in Switzerland, and spreads over large tracts in France, overlying the other and better known Tertiaries. It is partly marine and partly fresh-water. Among its fossil contents are several remarkable vegetable forms, one of which is figured in the annexed cut (fig. 171). It is interesting as marking palm vegetation, which must have existed

in Central Europe simultaneously with various trees hardly to be distinguished from those still inhabiting our forests. Dr. Göppert has remarked, that a great similarity prevails between the flora of the brown-coal and that of the United States of North America, in the Temperate Zone, varieties of Taxus greatly prevailing.

Fig. 171.



Palmacites Lamanonis (Middle Tertiary).

752. The valley of the Danube exhibits deposits of some extent belonging to the Middle Tertiary period, and extending from the neighbourhood of Vienna into Styria. These are not much unlike the others of the same date, and contain similar fossils. Amongst them are some bands of valuable lignite of enormous thickness.

The Miocene beds of Austria are cut off by the mountains of the Carpathian chain, but are again repeated to the north of these mountains by several patches on the left bank of the Vistula below Cracow, and in the provinces of Galicia, Volhynia, and Podolia. In these latter provinces, the great masses of gypsum and rock salt, which have been long celebrated, are supposed to belong to the period we are now considering.

753. Sir Charles Lyell and American authors have described contemporaneous deposits in the United States, consisting of green coloured sands and conglomerates, inclined at a high angle to the north-east, and well exposed in some localities. These seem to repose on argillaceous beds, and to be of considerable extent in some of the Southern States. They are fossiliferous; some part consisting, indeed, chiefly of shells and the remains of zoophytes.

754. The extensive and remarkable deposits found in the south flanks of the Sewalik hills in Northern India, have been referred, though somewhat doubtfully, to this middle part of the Tertiary epoch. Commencing at Saharunpore, these beds may be traced towards the south-east, extending to a very considerable distance, but nowhere south of the Ganges. Beds of the same age are repeated at two very distant points, one near Bombay, on the western coast of India, and the other at the mouth of the Irrawaddi river, in the peninsula of Siam.

755. The formations composing the Sewalik hills, which have sometimes been called the Sub-Himalayans, consist of beds of boulders or shingle, of sands hardened to every degree of consistency, of marly conglomerate, and of an infinite variety of clays. The strata dip from 15° to 35°, generally towards the north, and the breadth of the inclined beds is from six to eight miles.

In that part of the Sewalik district west of the Jumna, there is an interminable series of clays and sandstones, the former being in greatest abundance, and the whole dipping at an angle of 20° to the north, and extending to the plain of the Jumna.

756. Chiefly in the upper part of this series there occurs a sandstone rock, which is generally soft and containing but few fossils, but in some parts extremely fossiliferous, and in that case so hard as to turn the edge of the chisel, protecting the fossils from destruction, even when they are rolled as boulders along the beds of the mountain torrents. Fossil bones have been found also in great abundance on the surface of the slopes near the sandstone, and amongst the ruins of fallen cliffs; they include several genera of Pachydermata, Carnivora, Ruminantia, and even Quadrumana, besides the bones of Crocodilian animals and Tortoises, many of them extremely remarkable, and indicating the former existence in this part of the world of races of animals very different from those now inhabiting the district. Most of the species are new, and there appears to be scarcely a limit to the variety, as well as the abundance, of these remains.

757. The hills of the Sewalik range, between the Jumna and the Ganges, consist of alternations of sand and clay similar to those just described; but these are overlaid by beds of shingle of enormous thickness, which also alternate with the sandstone. Carbonaceous matter occurs (sometimes in the form of lignite) throughout the sandstone, and the trunks of dicotyledonous trees are found in great abundance. Marls, also, are here associated with the upper beds, and contain, like the upper sandstones to the west, vast multitudes of fossil remains, chiefly of Mammalia and Reptiles. These fossils are remarkably perfect, and are usually of a deep black colour, owing to the presence of iron. The greater part of them have been obtained from a deposit in the Kalowala Pass.*

758. The contemporaneous beds on the west coast of India, occur in a conglomerate which appears to extend widely near the entrance of the Gulf of Cambay, but which is much covered up with Newer Tertiary and recent accumulations. The variety of fossils found here is considerable, and completely identifies the deposit with the Sewalik tertiaries already described.†

5. *Older Tertiary Period.*

759. The Older or Eocene Tertiary deposits are on the whole much more distinct and important, and can be more safely referred to a definite period than any of those we have yet considered. They are well developed in various parts of the world, and demand the careful attention of the student in their different localities. Like many other series they vary much in local character, but they expose a former condition of certain parts of the continents of Europe and North America so different in climate from that which now prevails, as to evince an entire change in the disposition of the land since the date of their deposit.

These beds are found in England chiefly in the basin of the Thames, and in Hampshire near Southampton. Small portions are also found occupying the northern part of the Isle of Wight. On the continent

* "Ansted's Geology," vol. ii. p. 95.

† See "Quarterly Geol. Journ.," vol. i. p. 359.

the beds near Paris are of the same age, but are totally different in mineral condition. Brussels also is built on contemporaneous deposits, and we shall have occasion to mention numerous other localities of great interest.

760. In describing the Middle Tertiaries we have spoken of the sands underlying the fresh-water beds containing Limnea and Planorbis. These sands are the Fontainebleau beds, and form the uppermost portion of the Lower Tertiaries. Below them are other fresh-water beds containing gypsum, and then the middle sands called "grès de Beauchamp," making in all a thickness of about 280 feet of beds, all of which are unrepresented in England. Next follow the well-known, but not very extensive deposits, called "Calcaire grossier" and "Glauconie grossière," represented by the far thicker and more extended sandy and clayey deposits of the upper part of the Hampshire system, and in the basin of the Thames by the Bagshot sands, after which we have the London clay in the latter, and the Bognor beds in the former district, and the mottled clays and sands on which these repose, representing on a grand scale the lower sands of the Paris basin. The following table, arranged from that given by Mr. Prestwich, may be safely depended on as affording a correct view of the relations of these deposits.*

LONDON.	Average thickness in feet.	HAMPSHIRE.	Average thickness in feet.	PARIS.	Average thickness in feet.
				Millstones and clays ..	80
				Upper fresh-water marls and limestones .... Gypseous series .... Lower fresh-water marls and limestones..........	150
				Grès de Beauchamp ..	50
		Fluvio-marine and Fresh-water series	350	Calcaire grossier, and Glauconie grossière.	100
		Barton clays	300		
Bagshot sand	400	Bracklesham sands..	700		
London clay	350	Bognor beds	250	Sables inferieurs (part)	100
Mottled clay and sand	80	Mottled clay and sand	150	Argile plastique	60
	830		1750		540

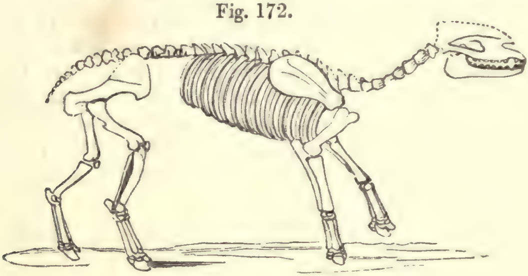
761. The important relations of the Lower Tertiary deposits in these three districts will be at once seen in the above table, by which it appears that the upper part of the series is only presented in the continental locality, the middle part chiefly and most perfectly in Hampshire, but also in each of the other two, while the lower mem-

* See "Quarterly Geol. Journ.," vol. iii, p. 400.

ber is most important in the basin of the Thames, but well represented also in Hampshire and Paris. The lowermost member of the series is nearly the same in each locality, but the others differ greatly. We proceed to consider some of the most interesting points with respect to each of the principal divisions.

762. The gypseous series of the neighbourhood of Paris is interesting and worthy of notice, both for its fossil contents and its mineral composition. It consists of a siliceous limestone of fresh-water origin, occasionally alternating with, and sometimes covered by white and green marls, with a considerable quantity of gypsum, the latter being chiefly developed in the centre of the basin-shaped depression in which the Tertiaries are there deposited. These beds contain land

Fig. 172.



Skeleton of Palæotherium
(Paris Basin).

and fluviatile shells, fragments of wood, and great numbers of the bones of fresh-water fish, of crocodiles and other reptiles, of birds, and even of quadrupeds, the latter being usually isolated, and often entire. The gypsum beds have been extensively quarried for the manufacture of "Plaster of Paris" (obtained by burning the gypsum), and have yielded a multitude of mammalian remains, of which the above diagram (fig. 172) will give some idea. It is chiefly the lower part of the gypsum which may thus be regarded as a great charnel-house of extinct quadrupeds; but the uppermost strata, composed of thick beds of marl either calcareous or argillaceous, are also worthy of notice, and contain numerous silicified trunks of palm trees.

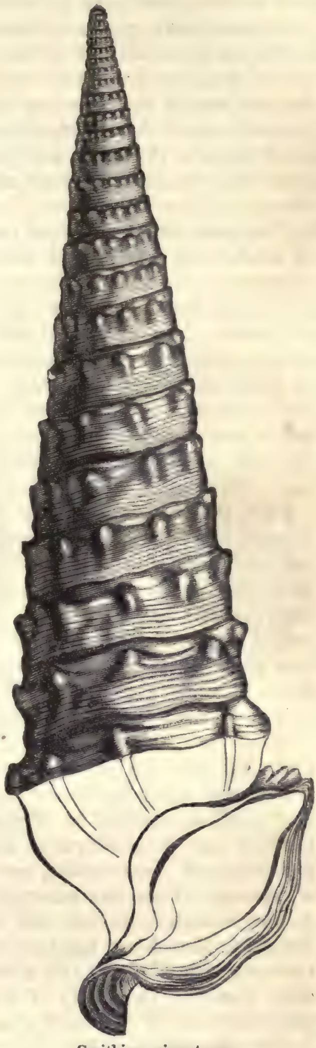
763. The beds next in order in the neighbourhood of Paris are those which have been long known as the *calcaire grossier*, and they are not less remarkable for their fossil shells than the former are for their abundant remains of quadrupeds. They consist of coarse limestones, often passing into sands, and alternating with clayey and calcareous marls and hard limestones. Nearly a thousand species of shells are contained in the calcareous sands, and amongst them have been determined no less than 140 species of one genus, *Cerithium*,

usually an inhabitant of brackish water. One remarkable and gigantic species is figured (see fig. 173), and often attained a length of upwards of a foot.

764. The fluvio-marine and fresh-water beds of the Hampshire basin are best exhibited at Headon-hill (Alum Bay), and also at White-cliff Bay, in the Isle of Wight, where they form a large series of sands and limestones containing fossils. The Barton clays which next succeed, and the Bracklesham sands, have generally been regarded as contemporaneous with the London clay of the Thames basin, but must now be regarded as higher in the series. They include a considerable variety of fossiliferous clays containing more or less marl and sand, and may safely be referred to the period of the calcaire grossier.

765. The Bagshot sands have only lately been so far made out as to be referred with satisfaction to any particular part of the Tertiary series, but since the investigations of Mr. Prestwich, they must be looked on as the true and somewhat important representatives of the Bracklesham sands, and, therefore, as immediately succeeding in age, as well as position, the beds of clay known as the 'London clay.' They consist of three principal members, the middle part containing clayey deposits, and occasionally presenting fossils, while the upper and lower are almost entirely siliceous, and fossils are exceedingly rare. They usually form barren and heathy districts, and are frequently found covering the true London clay.

Fig. 173.



Cerithium giganteum
(Older Tertiary).

766. The London clay, represented in Sussex by the more compact and concretionary beds found at Bognor, is a well marked and peculiar deposit, generally between 200 and 350 feet thick, and reposing on an important series of mottled clays, sands, and pebbles of the same age as the "Argile plastique" of the vicinity of Paris, and for that reason the beds are not unfrequently, though very inappropriately, called the Plastic clay formation. These mottled clays and sands have a thickness sometimes amounting to 150 feet, and are often very distinct in their mineral character from any associated deposits.

The middle and principal portion of the London clay is generally of a blackish colour, and tough, but is often mixed with greenish-coloured earth and white sand, and occasionally encloses layers of oval or flattened masses of clayey limestone, called "septaria," which are traversed in various directions by cracks, filled completely with calcareous spar, and are particularly abundant in the neighbourhood of Harwich, where they are much used in the manufacture of "Parker's Cement." Many parts of the London clay contain, also, hard bands, either calcareous or siliceous, and sometimes fossiliferous, and the cliffs of Harwich occasionally include, besides the veins of septaria, other beds of true calcareous matter.

767. On the continent of Europe there are several localities in France, besides the Paris basin, where Eocene Tertiaries occur, and we have already mentioned the deposits on which Brussels is built, as having the general characters of the London basin. In Northern Italy, in the neighbourhood of Nice, is a nummulite rock of this period; and at Monte Bolca is a remarkably fossiliferous limestone, also contemporaneous, and containing numerous remains of fishes, while in many parts of the Mediterranean other beds, also fossiliferous, have been found, of whose Eocene age there can be no doubt. Besides these, however, we also find widely developed, not only in Italy but in the Alps, the Apennines, and on both flanks of the Pyrenees, and again in Greece, Asia Minor, and Egypt, a very important and thick deposit, often of a calcareous nature, chiefly remarkable for the vast preponderance among its fossils of a Foraminiferous genus named *Nummulites*, so called from its resemblance to a piece of money. This has generally been referred to the cretaceous or Newer secondary period, but it is at least partly Tertiary, and Sir Roderick Murchison has lately endeavoured to prove the necessity of referring the whole to this newer date. However this may be, there is no doubt of the study of these beds proving of great interest, and affording one of the chief connecting links between the deposits of India and those of Europe. The importance of following out this question may be judged of when it is remembered that this nummulitic formation "extends at intervals through no less than 25 degrees

of latitude, and near 100 degrees of longitude, its northernmost ridge on the north flank of the Carpathians being clearly identifiable with its southernmost known limb in Cutch, and its western masses in Spain and Morocco being similar to those of the Bramahpootra."*

768. We next proceed to the consideration of those fossils of the group which are most valuable as giving an idea of the actual condition of the earth at the time of the deposits of this period; and here we at once remark, that so far as the British Islands serve as the indication, there is strong proof of a great change having occurred, since the general character of our Eocene fauna and flora is tropical. With one or two exceptions, indeed, all the species are extinct, and do not range to formations either above or below.

Fig. 178.

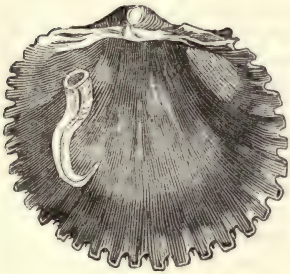


Fig. 180.

Fig. 177.

Fig. 179.

Fig. 175.

Fig. 176.

Fig. 174.

Group of Fossils of the Eocene period.

Fig. 174. Orbiculina numismalis.
" 175. Bulimina Murchisonii.
" 176. Sagrina rugosa.
" 177. Venericardia imbricata.
" 178. Serpula in Cardium porulosum.
" 179. Ampullaria acuta.
" 180. Turitella imbricataria.

The fullest catalogue of British Eocene fossils (Mr. Tennant's) gives the number as follows: Plants 100; Zoophytes, 4; Echinoderms, 5; Foraminifera, 8; Annelida, 11; Cirrhopoda, 3; Crustacea, 4; Con-

* Murchison on the Structure of the Alps. Quart. Geol. Journ., vol. v. p. 305.

chifera and Brachiopoda, 235 ; Gasteropoda and Cephalopoda, 267 ; Fishes, 97 ; Reptiles, 14 ; Birds, 1 ; Mammals, 14. In addition to these, however, a very considerable number of species occur exclusively in the Paris Basin, so that upwards of 3000 species in all have been referred to by Professor Bronn, in his tables already more than once referred to. Of these, 57 are Mammalia and as many as 136 are referred to the Vegetable Kingdom. The remains of plants in the Older Tertiary beds are, however, chiefly fruits, and are almost entirely obtained from the London clay beds of the Isle of Sheppey, though other localities are known.

769. The invertebrated animals show a large preponderance of the ordinary genera of mollusca, and of these a few are represented in the group of figures annexed (figs. 177—180). There is, however, a manifest departure from recent specific forms, especially those inhabiting the immediate vicinity, and, as we have mentioned above, a tropical character is traceable in the whole arrangement of the group. When we regard the higher organisations, as those of vertebrated animals, we find a much further departure from existing local types, and this is seen the more strikingly as we advance towards the higher mammals. The fishes, chiefly met with in the London clay, the beds of Monte Bolca and those of Mount Lebanon, offer representative species of a large number of genera and natural families, of which the modern species are well known. The following short comparative table will, however, give the best notion of these relations.

	British species now existing.	Fossil species in the London clay.
Perch family	7	7
Mackerel family	11	12
Cod family	20	4
Herring family	8	2
Eel family	8	1
	54	26

To this we may add, that four of the recent families richest in species now, are either without a single Eocene species, or are very sparingly represented, while on the other hand and in their place we find three extinct genera of one family, now almost confined to the southern seas ; one of a family now absolutely tropical, and five of another family now almost limited to the Mediterranean.

770. The reptiles of this period, like the fishes and shells, show a marked resemblance to the inhabitants of much warmer and more insular climates than those met with at present in the Temperate Zone of the Northern Hemisphere. They include several lacertian and crocodilian animals ; some turtles and tortoises, and some gigantic serpents, which attained a length of from ten to upwards of twenty

feet. The remains of birds are not wanting to add to the evidence of this kind.

The land quadrupeds of the Eocene period in Europe, include several species, all extinct, and most of them referable to the order *Pachydermata,* which seems to have been, to a certain extent, the representative form at that time of the existing groups of Ruminants. Amongst the fossils must also be mentioned, the remains of a monkey, a bat, and a few carnivora.

771. The North American representatives of the Eocene rocks are chiefly found in the Southern states of Virginia, Carolina, and Georgia; and consist, in Virginia, of green sand and marl, accompanied by green earth, precisely like older beds belonging to the upper secondary series of New Jersey, but containing very different fossils. Further to the south the nature of the deposit changes, and highly calcareous white marls and white limestones appear, which are covered by red and white clays, ferruginous sands, and associated layers of burrstone and siliceous rock. In other places a white limestone (Santee limestone) characterises these deposits, and has led to the idea that a passage downwards existed to the cretaceous rocks. Sir C. Lyell, however, has found that no such passage is indicated by the fossils. About 125 species of Eocene American fossils are mentioned by Sir C. Lyell as determined on good authority; and of these only seven are identical with European Tertiaries of this age. At least one fourth of the whole appear, however, to be very closely allied to European fossils of the same age; while another fourth differ greatly from any species obtained from the Eocene strata of Europe, although belonging to genera abundantly represented in these formations.*

772. South America unquestionably presents, on both sides of the Andes, Tertiary strata of very ancient date, referable to the Eocene period. These are of great extent, especially along the shores of the Atlantic; but the deposits on the two coasts differ almost entirely in their fossil contents. It would appear, however, that there is no evidence, in this part of the world, of the climate having materially changed, or at least none of its having been more tropical than it now is in the same latitudes. There is evidence of great change of level to the extent of 700 or 800 feet of depression along both lines of coast during this period; and in the newer deposits there is proof equally strong and satisfactory, of a large amount of elevation.

773. Among the minerals of importance obtained from Tertiary deposits, we may mention the stream-ores of gold, platinum, and other rare metals found with these; the similar deposits of tin ore; the lignites met with in various parts of Europe, Asia, and America; the fragments of amber from the shores of the Baltic, and the diamond gravels and sandstones of India and Brazil: of many of these some ac-

* "Quarterly Geol. Journ." Vol. i. p. 442.

count has already been given, and we only now add a brief account of the circumstances under which the two latter minerals occur.

774. Amber is found in nodules varying in size from that of a nut to that of a man's head; but the latter size is very rare. It is also met with on some sea-coasts, and near the mouth of some great rivers. It has been found in Sicily, Poland, Saxony, Siberia, and Greenland: also in our own country, on the Yorkshire coast. Even some of our clay pits have yielded it: for instance, in one near St. George's Hospital, Hyde Park Corner, excellent specimens have been found. But the situation in which it is obtained in most abundance is in East Prussia, along the coast of the Baltic, between Memel and Dantzic, especially along the shore near Königsberg.

Amber can seldom be obtained by mining operations; although pits are occasionally sunk in sandy downs to the depth of more than 100 feet, where it occurs in small quantities. The usual mode of searching for it is to explore the sea-coasts after storms, when the amber is found in nodules rounded by the sea, in a manner similar to pebbles on the sea-shore.

775. The way in which diamonds are obtained is by digging for them in the beds of torrents, or among the mud and sand brought down by periodical rains, where it accumulates chiefly on one bank, at the mouths of some of the smaller streams, and in the low shifting islands along the shore. They are found in India in the river Mahanadi, from Chunderpore, where the river Maund joins the main stream to Sohnpore, where the Mahanadi makes a sudden bend to the left, producing an extensive mud bank on the northern shore, making altogether a course of 120 miles. Throughout this extent the diamond-searchers ply their trade from the time when the rains cease until their periodical return.

The process of exploring is exceedingly simple, and the only tool employed is a sharp pickaxe. With this tool the men dig into every promising spot, and deposit on the banks of the river all the mud and sand they get up. There it is looked over by the women and children of the tribes, who for this purpose take a plank five feet in length by two in width, hollowed out in the middle, and furnished with a rim on each side three inches in height: they place this plank in a position a little inclined, just enough to allow water to run off, heap upon it the mud and sand dug from the river, and continue for some time to pour water upon it. As soon as the water runs away perfectly clear, they anxiously look over the hard stony matter which is left upon the plank, and pick out all the loose pebbles and larger pieces of gravel; these they throw away, and the remaining mass, consisting of smaller grains, they remove to another plank of the same form as the first, but smaller, and spread it carefully over the surface, so that every particle can be separately examined; this they

do one grain at a time, throwing away all that is merely stone or gravel, and laying aside every particle of gold or crystal of diamond. They usually contrive to place the board so that the sun shall shine upon it at a certain angle during this operation, so that every particle shall be well illumined. The earth chiefly sought after, and most accurately examined, is a red ochry clay, containing a small proportion of oxide of iron; in this the diamond is most commonly found; though, as it is sometimes met with in the loose mud, the whole is well washed and examined.*

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776. The general result of the investigations of Tertiary deposits, may be summed up as follows: First, The European Tertiaries generally have been deposited not far from land, but in isolated patches, having little resemblance either in mineral character or fossil contents with those at any considerable distance. The land was, probably, insular throughout the greater part of the Northern Hemisphere, and gradually more so as we look back into the early history of the period: so that while the newer deposits are chiefly on present lines of coast and low river-valleys—except indeed where there is distinct proof of great local elevation within a short time—the older beds are more distinctly marked and far more indicative of permanent and important change; and they seem also to be more independent of each other. They are, besides, more varied with fresh-water marls and even with travertin and other deposits from fresh water. During this period there must, therefore, have been very considerable alterations of level; for when we look at the present elevation of several beds, which must certainly have been formed in tolerably deep water, no doubt can remain as to this point. In addition, however, to the mechanical deposits which we have hitherto exclusively considered as of Tertiary origin, we must now take into account the marks of igneous action, and the metamorphoses that have altered the condition of various large mineral masses during the time. Thus, in Central Europe, south of the Alps, we find striking proofs of change connected with recent volcanoes; and these are not confined to the neighbourhood of Vesuvius and Etna, but extend to the northern part of Italy, and are no less clear in the Euganean Hills than in Sicily. On the north-east coast of Spain, also, Catalonia affords convincing proofs that Nature was not idle. In Greece similar effects have been produced, and like causes have been at work; while in Central France, and on the banks of the Rhine, the ancient volcanic craters may still be traced, and the erupted products yet remain, forming hills and filling up valleys, and mingled with various organic remains that mark, in many cases, the date of eruption. But are there, it may be asked,

* "Penny Magazine," vol. vii. p. 447.

no other marks of change? The study of the Alps, difficult and complicated as it is, has certainly answered this question in the affirmative; and at whatever age those grand movements of elevation commenced, which have uplifted the East and West mountain-chains of the Old World, it cannot for a moment be doubted that throughout the whole of the Tertiary period this line was becoming more distinct, the mountains loftier, the valleys deeper, and the various deposits more completely modified from their original condition. Besides the Alps, however, numerous other mountain-chains of lower elevation may be traced in Europe; and one of the most eminent living Geologists (Elie de Beaumont) has endeavoured to bring together the known facts with regard to these, and to draw important generalisations concerning the age of each. Although these views have been admitted by most recent French writers without question, and are certainly of great interest and value, we do not propose here to relate them in any detail, nor could we venture to discuss their truth and reality in the limited space of the present volume: we shall, therefore, conclude this chapter by first mentioning the principal periods of elevation during the Tertiary period, as given by M. de Elie de Beaumont, and then giving a general statement of the changes of the Tertiary epoch.

777. It is considered then that there have been five principal directions of elevation during the deposit of Tertiary beds, besides one during which the earlier beds were accumulated. It will, however, be more convenient in describing them, to commence with the earliest movements, and so proceed in order of occurrence. The first period of disturbance, then, during the Tertiary epoch, is supposed to have brought the Pyrenees into their present place, or at least to have removed the chalk from its original horizontal position before any of the Tertiary deposits had been made. It is believed that the same elevatory movement produced at the same time the nearly parallel mountain-chains of the Apennines, the Julian Alps, the Carpathians, and many alps in Eastern Europe, besides numerous dislocations in the north of France and the Wealden district in England and in Germany; thus being one of the most widely extended and important disturbances that has affected Europe. Its direction is stated as being W. 18° N. and E. 18° S.

778. The next principal elevation is supposed to have taken place between the Older and Middle Tertiary periods, to have produced the chain of Corsica, and to have upheaved the Paris basin, the valleys of the Loire and the Garonne, the whole of Switzerland, and the valley of the Rhone, besides producing many smaller lines of elevation in Italy. Indications of the same disturbance are supposed to be traceable in the Jura Alps and in the eastern part of the Mediterranean. The direction of the movement is considered to be north and south.

779. The next system is that of the Western Alps, and is supposed to have originated between the deposit of the Middle and Newer tertiaries. It is imagined that the lofty elevations of Mont Blanc and Monte Rosa are due to this elevation, but that it is traceable very far, reaching even to Scandinavia in the north, and to the Atlas Mountains of Africa. Its estimated direction is S. 26° W. and N. 26° E.

780. The next is the system of the principal Alps, supposed to range W. 16° S. and E. 16° N., including the whole range from the Bernese or Western Alps, from the Valais to St. Gothard, and extending eastward into Austria. Besides this, almost the whole of Europe is believed to have participated in the same movement.

781. The last great elevation is assumed to have taken place after the Drift period, and to have produced certain dislocations and elevations in Tuscany, South Italy, and Greece, and also in Sardinia and the coast of France. Its direction is described as N. 20° W. and S. 20° E. It is called by M. de Beaumont the System of Tenare.

782. It has also been suggested that these directions may prevail in synchronous elevations in other parts of the world, and thus that the mountains of Brazil may have relations with those of the Western Alps, and the Himalayans with the principal Alps. But it must be admitted that the generalizations already made concerning this subject are sufficiently wide, if the difficulty of estimating the true direction of a mountain chain and the true parallelism of any two chains are taken into account.

783. The following view of the changes experienced by the oceans and seas during the Tertiary epoch will fitly conclude the present chapter. It is from the account of the Geological Map of the World in Johnston's edition of the Physical Atlas already quoted. "During this epoch the Mediterranean, or another great and corresponding inland sea, covered the deserts of Sahara, Lower Egypt, and part of Arabia; for not till long after the commencement of the period were the present contours defined, and the lagunes and ancient shores left dry. Later still, the strait of Gibraltar probably did not exist, and the waters of our inland sea mingled, through the channels of the Red Sea and Persian Gulf, with those of the Indian Ocean; which seems to explain the analogy of the fossils of the Middle and higher tertiary Mediterranean beds with creatures still living in the Red and Indian Seas, and with fossils of corresponding age in the great basin of the Black Sea and Caspian. At the same epoch too, the North Sea and the Baltic spread over the plains of Northern Europe; and another ocean stretched from the recesses of Siberia, and joined with the Mediterranean, by the Black Sea. Asia Minor contained small isolated basins; though the Black Sea, on the south and east, was confined by its present banks. In the south of Asia, a broad strait severed the peninsula of India, then a triangular island, from the

chains of the Himalaya and their dependents; and there existed also a great fresh-water basin in the peninsula beyond the Ganges, two other basins at least in China, one on the banks of the Lower Amour, and two in Siberia. As in the case of Europe, the centre of this continent was covered by an inland sea, which has now wholly disappeared. Other aqueous masses covered Persia, and probably formed, later even than the Tertiary epoch, one basin dependent on the Caspian, and another annexed to the Indian Sea. In another district of the continent, large portions of the isles of Sunda, the Philippines, Borneo, New Guinea, and Australia were at this period under the waters; and many volcanic peaks now existing, and belonging to great areas of elevation, had not yet risen above the surface of the Indian or Malay Seas. Turning to the map of America, we discern evidence of changes equally singular and extensive. The Gulf of Mexico then penetrated deep into Mexico, Florida, the lower basin of the Mississippi, and also into the basins of the northern rivers of South America. It washed the southern extremity of the Alleghanies, as well as the feet of the Ozark Mountains, and the Mexican and Columbian platforms. Farther north, a great interior ocean overspread part of this continent, comprehending the higher Mississippi, and the great lakes. The Gulf of Mexico already contained a few islands composed of old formations, probably of much larger size than those whose shores it now washes; but its volcanic isles sprung into existence subsequently, during that series of subsidences and elevations, of *écroulements* of the chains along the ancient shore of South America, which drove the sea from the Ozark Mountains and the Alleghanies, and fixed its limits farther south. The northern part of the continent had three islands, the basin of the St. Lawrence separating the district of the Alleghanies from dry land on the banks of Hudson bay, and perhaps bending round to the Icy Sea. The platform of Mexico and Guatemala formed an appendix of the long isle of the Rocky Mountains; and the Ozark Chain advanced into the waters. The volcanoes of continental America, as we see them now, were contemporaneous with the formation of the Mexican and Mediterranean basins. In South America we discern abundant proof that, at the Tertiary epoch, the Atlantic covered the great strait between Brazil, the Andes, and central Guayana, as well as between the Parima and the chain beyond the Orinoco; whence the mingling of the tributaries of this river and the Amazon, as well as the mode of the division of the waters between certain affluents of the La Plata and the Amazon. South America was then composed of three great islands; for the isthmus of Panama did not exist."

CHAPTER XV.

ON THE ROCKS AND FOSSILS OF THE SECONDARY EPOCH.

784. The deposits of the Secondary epoch so far as they have been as yet examined and described in various parts of the world, may with some convenience be divided into four principal groups, each of which again presents well marked subdivisions. Although these have been already stated in the general tabular view of formations at the close of Chapter xiii., we here repeat the chief divisions before proceeding to describe the rocks in detail.

Cretaceous system	1. The Upper cretaceous series. 2. The Lower cretaceous or greensand series.
Oolitic system	3. The Wealden series. 4. The Oolitic series.
Liassic system.	
Triassic system.	

1. *Upper cretaceous series.*

785. The Cretaceous or newest division of the Secondary or Middle period is very well exhibited in many parts of Europe by the chalk, a calcareous deposit too well known to require further description. Below the chalk and other nearly contemporaneous rocks there occurs an important group of sands called by French and other continental writers *Neacomian,* as being typically represented in the neighbourhood of Neuchâtel in Switzerland, but in England usually spoken of as the "Lower greensand formation," that name having been long familiar to English geologists. We shall find it convenient to describe the upper and lower divisions of this system separately.

The divisions and usual synonyms of the upper members of the Cretaceous system are pretty much as follows, but they vary in particular localities, the names of the beds requiring modification in distant localities, and becoming inapplicable where they have reference to mineral structure. It is only in England and Europe that characteristic names have been given, and the corresponding beds in America are quite distinct in mineral character. In the subjoined table the names of the principal subdivisions are given, and such synonyms added as are likely to be found useful.

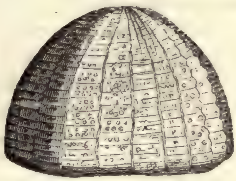
English, Danish, and Belgian series.	French series.	German series.
Chalk of Faxoe, Denmark. Maestricht beds, Belgium. Upper chalk, with flints.	Terrain senonien.	Upper Quader sandstone
Middle and lower chalk, (without flints) and Clunch.	Terrain turonien. *a.* Craie chloritée. *b.* Glauconie crayeuse *c.* Craie tufau.	Upper Pläner limestone.
Chalk marl. Upper greensand. Gault.	Terrain albien.	Middle Pläner. Lower Pläner.

786. The *Chalk* is a remarkable and familiar rock widely distributed not only in England, but in many parts of the continent of Europe. It is a nearly pure carbonate of lime,* containing, Lime 56·5, Carbonic acid 43·0, Water 0·5, and having a specific gravity of 2·3. It absorbs water readily. With the chalk are usually found either bands of black flint or disseminated silex, the flints being generally in the upper portion, and the lower beds more mixed with sand, calcareous matter, and iron. Fossils are found in the chalk very commonly, but by no means universally. Among those in the upper beds are several Infusoria and Foraminifera, and numerous small corals ; many species of sea-urchin (fig. 181), many of the remarkable shells spoken of in a former paragraph (§ 145) as

Fig. 182.

Fig. 183.

Fig. 181.



Group of Chalk Fossils.
Fig. 181. Ananchytes ovatus (Upper chalk).
,, 182. Hippurites organisans (Lower chalk).
,, 183. Plagiostoma spinosum (Upper chalk).

Rudistæ, one of which is there figured, and another is represented in the annexed figure (182). There are also numerous bivalve shells (fig. 183 is a very common species), besides remains of Cephalo-

* The following analysis of chalk from Denmark by Professor Forchhammer has been very recently published :—

Carbonate of lime	98·779
Carbonate of magnesia	·641
Phosphate of lime	·011
Silica	·352
Loss	·217
	100·000

poda (figs. 157, 158), Crustaceans, Fishes, and Reptiles. The chalk is a deep sea deposit, and is unlike any rock now known to be in the course of formation, though it may be compared with deposits resulting from the finely powdered mud accumulated in coral lagoons.

787. The Upper cretaceous rocks are but little made use of in England except when burnt into lime, or mixed with other soils for agricultural purposes. The Lower and harder beds have, however, been employed for internal work occasionally, in cathedrals and other large public buildings, and they stand well if not exposed to accident from mechanical violence. Clunch is the name usually given to the varieties of this kind.

788. The Chalk ranges through England in a north-easterly direction from Hampshire to the Yorkshire coast, running out in two spurs to the east, one proceeding along the south coast, forming the South Downs, and terminating at Beechy Head; and the other forming the North Downs, and extending to the sea at Dover. The Tertiary deposits of the London and Hampshire Basins cover up and conceal much of the deposit. Chalk occurs in Ireland on the north-east coast, but is there partly covered and altered by basalt. The average thickness of the chalk in England is generally estimated at about 1000 feet.

789. Crossing the channel which separates England from the continent the white chalk may be recognised forming cliffs on the shores of France opposite both Dover and Beechy Head, and the bed recurs in Denmark in a line continued from the Yorkshire coast towards the north-east. Rocks of the same kind and of contemporaneous date range eastwards through a great part of Europe often in a much harder state than in England, and without the peculiar aspect of the deposit. In Poland, however, true white chalk is again found, and extends to the south of Russia, covering the plains of Moldavia, and constituting the western part of the Crimea. In the chain of the Caucasus beds of the Cretaceous period, consisting of pure white chalk, flank the metamorphic rocks of the central axis of the mountain ridge, and even put on something of the physical aspect of the Downs in the south-east of England.

790. Although totally different in mineral character the Upper Quader sandstone of North Germany is a contemporaneous rock, generally a sandstone of loose texture, and extremely barren in organic remains. Only about 30 species have been obtained from it, whilst the whole number of chalk species is stated by Bronn to amount to nearly 3000.

791. In many parts of South Europe, North-eastern Africa and Asia, there are found bands of limestone containing fossils, chiefly either corals or Foraminifera, one genus of the latter being especially common, and from its resemblance to a piece of money very easily

recognised. These fossils, called *Nummulites*, are found both in lowest Tertiary and uppermost Secondary deposits, and cannot be considered to mark the exact age of the beds, but they are valuable indications, and often the only ones present. Nummulite limestones occur in Asia Minor, and may be traced at intervals along the wide tract of country between the Mediterranean and Western India. Similar rocks occur in North Italy, but are there certainly of older Tertiary date, and have been already alluded to. The opinion recently adopted by Sir R. Murchison of the contemporaneity of all Nummulitic beds we are not inclined to put forth at present as generally admitted, and it is, perhaps, safer to regard many of the Italian foraminiferous rocks, and much of the *Macigno*, so widely distributed in Southern Europe as of doubtful age, while others, among which the *Alberese* is most remarkable, is a deposit unquestionably cretaceous. The uppermost of the beds, called by Italian geologists *Scaglia*, is also a representative of the chalk.

792. The Upper chalk of England is remarkable for containing bands of nearly pure, black, siliceous concretions well known as *flints*. These appear to possess in many cases an organic centre or origin, but have not unfrequently been segregated long subsequently to the original deposit of the bed. In the lower part of the chalk true flints are rarely found, but instead of them grains of silica are mingled with the rock as an impurity, and are often accompanied by a good deal of argillaceous matter. The lower bands thus characterised are known by various names, of which *Chalk marl* is, perhaps, the most convenient, and they are not unfrequently coloured with green particles of silicate of iron, or dark red particles of the oxide of the same metal. These beds are represented in France by the lower members of the "Terrain turonien," which exhibit nearly the same peculiarities as in England, though to somewhat greater extent. In Germany the "Upper Pläner" is a marly limestone of clear grey colour containing about 75 per cent of carbonate of lime.

793. Below the Chalk marl appear bands of still more argillaceous and siliceous character, the limestone passing often into a greenish calcareous sandstone coloured by silicate of iron, and thence called the *Upper greensand*. This deposit is generally represented by arenaceous beds or true sandstones in Saxony, and by somewhat similar beds in France. The following account of the Upper greensand will be sufficient to give a general idea of its character in England.

This bed is not extensively shown in the South-east of England, but there is no doubt of its actual presence. Between Godstone and Reigate, in Surrey, it begins to assume a decided character, and is quarried for a particular kind of sandstone, called "fire-stone," which is valuable for lining fire-places and furnaces. Still further to the west, and near Petersfield, it runs out beyond the foot of the

chalk escarpment, passing insensibly into the Lower chalk, but the whole of the terraces (which are at least two miles broad) are exclusively composed of this bed, locally called the "Malm-rock."

Something of a similar step-like appearance may also be observed in the Isle of Wight, and especially at Black Gang Chine, where the bed has a thickness of about 100 feet, the lower part being sandy, with spongiform masses, and the upper part containing abundance of chert, or hard siliceous rock.

794. Proceeding northwards to the Vale of Wardour, the Upper greensand is still well represented, the whole series of beds of which it is composed rising abruptly on the north side of the valley, and forming a narrow ridge of unequal height. The thickness here is as much as 50 or 60 feet, and the upper beds contain chert. In North Wiltshire the formation occupies a slightly prominent step below the foot of the chalk, but towards the north-east it becomes less and less important, until, in Bedfordshire, it is not more than seven feet thick, although it still retains its cherty character. In Cambridgeshire even this peculiarity is gone, but there remains about 18 inches of a soft sandy mass (rarely containing green particles), separating the Gault from the Lower chalk. The bed, however, though thus debased in its character, is remarkably persistent throughout; and further north it again contains chert and firestone, and is finally observed developed in its characteristic form on the Norfolk coast.

795. Before concluding this account of the Upper greensand formation notice should be taken of a remarkable outlier, forming the Blackdown Hills in the county of Devonshire. These hills are capped by about 100 feet of sandy strata representing the lower part of the Cretaceous system, and consist of layers of cherty concretions, alternating with loose sand. Four of the layers are worked for whetstones, the mines or pits being driven almost horizontally into the hill to a considerable distance, and the masses of which the whetstones are made varying from 6 to 18 inches in diameter. The looser stone is employed for building.

796. From these workings numerous organic remains have been obtained, often in fine preservation, and converted into chalcedony. Upwards of 150 species have thus been determined, of which 90 are not known to occur elsewhere in England, and the deposit must, probably, have taken place under circumstances somewhat different from those of the rest of the formation.

Amongst the fossils are some represented in the annexed group; these include, however, species from the underlying beds also.

797. The Gault—immediately overlying the Lower greensand—is rarely absent, and may, perhaps, be considered as the most persistent of all the subordinate beds of the Cretaceous group in England, scarcely ever changing its peculiarities of mineral composition or fossil

remains. At Folkstone, where it is seen in perfection, it rises gradually towards the west of the town, and forms a cliff about 120 feet thick, resting distinctly on the Lower greensand, the section being well exposed, and the stratum extremely fossiliferous.

Gault is a provincial term, used originally in the middle of England, to designate the brick clay, which there belongs to the part of the Cretaceous system we are now considering. It is a stiff clay of a blue colour, and the inferior portion of it abounds with iron pyrites, while the upper part contains green particles of silicate of iron.

Fig. 186.

Fig. 185.

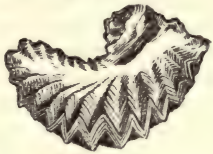
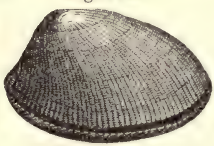


Fig. 187.

Fig. 184.



Group of Upper greensand and Gault Fossils.

Fig. 184. Nucula pectinata.
,, 185. Ostrea carinata.
,, 186. Ammonites Rhotomagensis.
,, 187. Turrilites costata.

Various nodules and concretions are found throughout, which are sometimes fossiliferous, but more frequently obscure, and of doubtful origin.

798. The following careful measurements of a section of the Upper greensand and Gault on the south-east coast of the Isle of Wight, is by Mr. Simms :—

		Feet.
Upper greensand.	Parallel layers of soft rock and chert	37
	Sand, with beds of stone and chert	67—104
Gault.	Light coloured gault.	43
	Blue gault. No fossils.	103—146
	Total	250

799. The 'terrain albien' of M. D'Orbigny, is the French representative of our Upper greensand and Gault, and puts on something of the same character. In the north of Germany the Middle Pläner, a sandy or marly bed, poor in fossils, represents the sandy, and the Lower Pläner, a very variable rock, often containing Hippurites, the argillaceous bases of the Upper cretaceous system. In the east of Europe the English types are repeated to a small extent; but still

further to the east they have not been recorded. There is a schist or slate in the canton of Glaris, in Switzerland, contemporaneous with our Gault.

800. In North America the newer part of the Cretaceous system is exhibited in several places, but nowhere in the same form as with us. The rocks there are loose sands, with calcareous bands. They afford lime, and contain lignites, and somewhat resemble the crag of Suffolk. They are presented at intervals on an irregular line, measuring nearly 3000 miles in extent. In the Texas there are contemporaneous rocks, consisting of hard compact siliceous limestone. In South America there are also cretaceous deposits of the age of our chalk, but they are not abundant.

2. *Lower greensand series.*

801. The lower part of the Cretaceous system is hardly less important than the upper, although in England it is much less perfectly exhibited. Along and near the south coast of our island, and at the back of the Isle of Wight, there are, however, large and important series of deposits referable to this series. The following is the arrangement as determined in England and on the Continent of Europe.

English series.	French series.	German series.
1. Argillaceous beds.	1. Terrain aptien. (Argile à plicatules.)	Lower Quader sandstones.
2. White and green sandy beds, and clay.	2. Terrain néocomien. *a.* Argiles bigarrées.	Hilsthon.
	b. Argiles ostréennes.	Hils-conglomerat.
3. Kentish rag.	*c.* Calcairè a spatangus.	
4. Atherfield clay.		

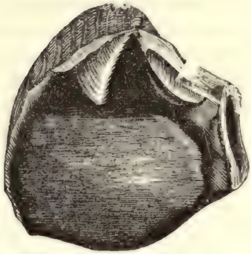
802. The uppermost member of the Lower part of the Cretaceous system in England is, as may be seen by the Table, a group of argillaceous beds—often ferruginous and containing some sands. Then succeeds a large group of white and green sandy beds, alternating with many clays, and then succeeds the bed called sometimes the Kentish limestone, or Kentish rag, which is of considerable value for various purposes, being used chiefly as rough building stone, and having a somewhat wide range in the south-east of England. These all appear in considerable thickness, the series at Hythe measuring 400 feet, and at the back of the Isle of Wight more than double that amount. The bottom of the whole series is a clay deposit, which seems to pass very insensibly into the underlying fresh-water clays of the Upper Wealden.

803. Many fossils are found in the English, and many others in the Continental deposits of this period ; one or two of the more cha-

racteristic and common of which are represented in the group annexed (figs. 188, 189). A proportion of the whole consists of species strictly confined to particular parts of the formation, and therefore, highly characteristic. (See also *ante*, figs. 145, 147.)

Fig. 188.

Fig. 189.



Fossils of the Lower greensand (Neacomian beds).
Fig. 188. Spatangus retusus.
,, 189. Trigonia alæformis.

804. The 'Plicatula clay,' or *Aptian formation* of some French geologists, is considered to be identical in position with the upper part of our series; while the so-called Neacomian beds occupy the place of the sands and stones of the middle part of the series. According to this view, so far from the Neacomian deposits representing our Wealden, which belongs to the Oolitic period, they do not even reach so far down as the base of the true Cretaceous series. It is, however, not improbable that some localities in France and Switzerland may really be older than our Kentish rag. The Lower Quader, the German representative of the period in Saxony and Bohemia, is a coarse sandstone of loose texture, having a calcareous cement and containing fossils towards the base; it is much used as a building material, the lower portion being well adapted for this purpose.

Deposits of this period possessing considerable interest, have been found in India near Pondicherry, and also in South America. They contain fossils analogous, though not identical, with those found in European beds of the same age.

805. The *Speeton clay* is a dark blue laminated bed, with nodules of clay ironstone, having peculiar fossils, but probably belonging to the base of the Cretaceous system. It occurs only near Scarborough, in Yorkshire.

3. *Wealden series.*

806. The Wealden formation consists of a very thick and varied series of arenaceous beds, based on imperfect limestones, and covered by a bed of clay. The whole series contains the fossil remains of land, fresh-water, and estuary animals, and of land vegetables. The group is interpolated between the uppermost beds of the Oolitic group and

the lower ones of the Cretaceous series; but it offers so many analogies with the former in the nature of its fossils, and passes so insensibly from it, that it has been considered a member of the Oolitic system.

The following is a tabular arrangement of the different beds in descending order, as they are observed in various parts of the south-east of England:—

1. *Weald clay*, with subordinate limestone (called Sussex marble) and sand.
2. *Hastings sand*, including the beds of Tilgate forest.
3. *Purbeck strata*, consisting chiefly of compact limestone alternating with clay, and resting on fissile limestone and the Portland beds.

807. The *Weald-clay*, the uppermost member of the Wealden group, though rarely of greater breadth than five or six miles, may be distinctly traced in England, in the counties of Kent and Sussex, coming out from under the lowest beds of the Cretaceous system. It is also visible on the coast of the Isle of Wight, and the highest portion, wherever it appears, consists generally of a blackish clay, in which are abundant fresh-water shells and other fossils.

The strata which form the base of this superjacent group consist of beds of sandstone and shelly limestone, with layers of argillaceous ironstone. The limestone is called "Sussex marble," and is strikingly characteristic of the Weald-clay in England, occurring in layers which vary from a few inches to more than a foot in thickness, and which are separated from each other by seams of clay or coarse friable limestone. It is almost entirely made up of fossil shells (*Paludina*), united by a calcareous cement into compact marble, and has been used, like the Purbeck marble, in the internal decoration of churches and cathedrals, and to make the small insulated shafts of pillars so common in Gothic architecture.

The limestone, however, is not the only one of the Upper Wealden strata which has been used for economical purposes, the argillaceous iron ore contained in it having been formerly worked on the borders of the once extensive forests of the Weald.

808. The *Tilgate beds* may be considered to occupy the upper place in the next or Hastings sand series: and they receive their name from having been formerly extensively quarried in Tilgate Forest, near Horsham. They consist of several bands of bluish-grey sandstone or rather calcareous grit, which are of no great thickness, and alternate with friable sandstones, some of them highly ferruginous, others of a white colour and without iron, and others again containing particles of lignite. The lower of these beds form a conglomerate, containing pebbles of quartz, which have apparently been transported from a great distance.

The lower beds of the Hastings sand are well seen in the cliffs near Hastings, and consist of a friable sandstone (in which caverns are excavated) based on beds of shelly limestone and grit, and alter-

nating with shale and clay. These strata are overlaid by another series of sandy beds, containing a fine building stone, and, together with the former ones, they abound with organic remains, chiefly those of fresh-water molluscs.

809. The Purbeck strata, the base of the Wealden formation, may be divided into two parts, the lowest of them being a coarsely fissile limestone, locally called "slate," which has been used for roofing and other economical purposes. This bed, together with a slaty clay with which it is associated, is of considerable thickness, and is succeeded by finer compact limestones, abounding with bivalve shells of the fresh-water genus "Cyclas." These compact fossiliferous limestones again alternate with clay, and include a thick bed, almost entirely composed of oyster-shells. The limestones of this part of the series are quarried for building purposes, as many as fifty-five beds of useful stone being known; and the whole thickness of the upper member of the group amounts to about 125 feet. The beds at the top consist chiefly of the remains of an univalve shell "Paludina," cemented together by carbonate of lime and a large proportion of green matter; they have formerly been much worked, and are well known under the name of Purbeck marble, formerly used in the internal decoration of cathedrals, &c.

810. Wealden deposits have been found on the coast of France, in the Bas Boulonnois, and contemporaneous beds are known in some parts of Scotland, and in the north of Germany. The latter are extensive and important, consisting chiefly of sandstones, and are developed to great thickness.

811. The fossils of the Wealden period are chiefly the remains of plants, a few fresh-water shells and crustaceans, several insects, and the bones of fishes and land reptiles; the latter of very great interest, of gigantic proportions, and including herbivorous as well as carnivorous genera.

812. Dr. Mantell, to whom we are indebted for the most detailed account of the Wealden formation, describes it as "a series of clays and sands, with subordinate beds of limestone, grit, and shale, containing fresh-water shells, terrestrial plants, and the teeth and bones of reptiles and fishes; univalve shells prevailing in the upper, bivalves in the lower, and Saurian remains in the intermediate beds; the state in which the organic remains occur, manifesting that they have been subject to the action of river currents, but not to attrition from the waves of the ocean."*

4. *The Oolitic or Jurassic series.*

813. This great series of deposits is divided naturally in England into three parts, the upper consisting of the Portland beds reposing on the Kimmeridge clay, the middle presenting the Oxford clay covered by the Coral rag, while the lower is far more varied, and includes numerous bands, chiefly calcareous, but many of them sandy and clayey.

* Geology of the South-East of England, p. 180.

The general appearance of the Oolites in England may be described as consisting of three ridges, running north-east and south-east (or rather north-north-east and south-south-west) with three extensive and rich plains intervening. The ridges represent the escarpment of the hard limestone beds of the Lower, Middle, and Upper oolites respectively, and the plains the softer and less coherent clays and shales alternating with them. The lower deposits lap over the great plains of the Lias on the west, and on the east the Upper greensand usually forms a low escarpment, capping the uppermost beds of the Oolitic series whatever they may be. In the centre of England, the upper beds are usually absent; in the west, and in the vicinity of Bath, the whole sequence is nearly perfect; in the south, the lower limestones form the escarpment, while the upper beds occupy an important place in the sequence; and lastly, in the north, it is chiefly the central portion of the system that is developed, the calcareous part of it there attains its maximum of thickness and importance.

814. THE UPPER OOLITES.—The beds of this age, which are called on the Continent the *Portlandian group*, are, so far as the British Islands are concerned, almost entirely confined in their development to the south of England, only that stratum of clay which usually forms the base of the group being exhibited in Yorkshire, in the vale of Pickering.

815. The group of strata containing the Portland stone, and exhibited in Portland Island, includes several layers of coarse earthy limestone, which rest on a bed of siliceous sand, mixed with green particles. This is called the Portland sand, and sometimes attains a thickness of as much as eighty feet in the west of the island, and forms a complete passage into the underlying clay.

Above the coarse limestones of the lower part, which usually consist of alternate hard and soft layers to a thickness of fifty or sixty feet, there are three beds of serviceable stone, interstratified with clayey or siliceous bands: fossils occur in all these strata, but they are rare in those beds of the stone which are worked to advantage for economical purposes.

816. In the upper part of the Portland series, there occurs a very interesting bed, about a foot in thickness, of a dark brown substance containing much earthy lignite. This bed, called "the Dirt-bed," seems to be made up of black loam, which at some distant period nourished the roots of trees, fragments of whose stems are now found fossilized around it. Wherever the dirt-bed is laid open to extract the subjacent building stone these remains of trees occur, and they are placed at such distances from one another as trees growing in a modern forest.

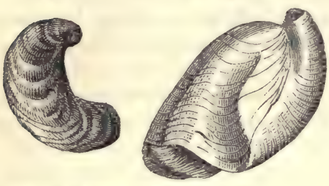
It results from the circumstances of this deposit that the surface of the Portland stone, at the termination of the Oolitic period, must have been for some time dry land, and covered with a forest; and we have a kind of measure even of the duration of this period in the thickness of the dirt-bed, which has accumulated more than a foot of black earth, loaded with the wreck of its former vegetation. "The

regular and uniform preservation also of this thin bed, over a distance of so many miles, shows that the change from dry land to the state of a fresh-water lake or estuary (which the nature of the overlying rock proves to have succeeded the period of dry land), was not accompanied by any violent denudation, or rush of water, since the loose earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe then taken place."*

817. The *Kimmeridge clay* is of a blue, slaty, or greyish yellow colour; it frequently contains a considerable quantity of selenite or crystallized sulphate of lime; it usually effervesces with acids, and exhibits in tolerable abundance both vegetable and animal impressions, although its fossils are rarely in such good condition as to be preservable in a collection. It is a bed of great thickness, horizontal, or nearly so, in its stratification, extremely persistent in its peculiar mineral and fossil characters, but not very extensively developed either in England or on the Continent. The name Kimmeridge clay has been applied to it because it is well exhibited at Kimmeridge Bay, and near the village bearing the same name in the isle of Purbeck.

At this spot there are also found, alternating with the clay, certain beds of highly bituminous shale, occasionally used for fuel, and locally known as the Kimmeridge coal. There are many beds of lignite found in the Oolites, but these are perhaps the most remarkable, next to those of the lowest Oolitic deposits of Yorkshire and North America. (See the note at the end of this chapter.)

Fig. 191. Fig. 190.



Shells from the Upper oolites.
Fig. 190. Terebratula sella.
,, 191. Gryphæa virgula.

818. The fossils of the Upper oolites, in England, include, as we have already seen, numerous remains of vegetables, and besides these are many univalve and bivalve shells, of which two are figured in the adjacent cut (Figs. 190, 191). Articulated and radiated animals are rare. Remains of fishes, of turtles, and of some marine saurians, occur, but no mammals.

819. Among the foreign rocks of this part of the Oolitic period are 1st. the *Calcaire de Blangy*, on the coast of Normandy; 2, the upper beds of the Jura, in Switzerland; and 3, the Solenhofen beds. The first are of the age of the Kimmeridge clay, but far more calcareous, and, indeed, the Upper oolites of the Jura approximate much more nearly than the other parts of the system to the Kimmeridge clay and Portland rocks. The former bed is represented with some

* Buckland and De la Beche. Trans. Geol. Soc. 2nd Series, vol. iv. p. 16.

accuracy by greyish schistose marls containing the Gryphæa virgula; but there is a prevalence of iron oxide in the deposit, and about forty feet of strata, in which pisolitic ore of this metal abounds, appear to be intermediate between the 'gryphæa virgula' marls, and the overlying limestones called *Portlandian.* This apparent peculiarity seems to be owing chiefly to the action of some cause by which the iron has been separated from the mass, and accumulated in a bed, instead of being left disseminated. Throughout the whole series the limestones predominate greatly over the argillaceous beds, and this appears to be most strikingly the case in the Jurassic district of the mountain chain of the Alps.

820. The sequence in the north and centre of Germany is nearly the same as in the Jura, except that the subdivisions are not so strongly marked, and that we find there a bed of great economical importance, namely, an exceedingly fine-grained fissile limestone of a rich cream colour, abounding in fossils, chiefly met with in the north of Bavaria, near the towns of Solenhofen, Pappenheim, &c., and exported to most parts of Europe for the purposes of lithography.

On the banks of the Donetz in South Russia there are beds of Oolitic limestone of light yellow colour, which appear to belong to this division of the secondary series.

821. THE MIDDLE OOLITES. These consist, for the most part, of a thick bed of clay, called the *Oxford clay,* widely expanded throughout England, and met with also in the same form on the Continent, and a series of overlying limestones chiefly remarkable for the abundant remains of corals found in them.

822. The upper beds of the Middle oolitic series are partly calcareous and partly sandy, the former consisting chiefly of a very interesting group of corals, known under the name of *Coral rag*, and the latter—the sandy beds (or *calcareous grits*)—often more or less intermixed with calcareous matter, and containing thin laminæ of clay sometimes passing into irregular bands of hard and tough marly rock. This calcareous matter seems entirely due to the presence of crushed and decomposed organic remains.

It is chiefly in Wiltshire, near the towns of Calne and Steeple Ashton, and in the surrounding neighbourhood, that the corals of the Coral rag are found in greatest abundance and perfection; and this part of our island at the time of the deposit, has clearly existed in the condition of a coral island in an open sea. The thickness of the bed is about forty feet; large portions of it are frequently made up of the remains of a single species, and an earthy calcareous freestone, sometimes used as a building-stone, and full of fragments of shells, rests immediately upon it, and is surmounted by a fine grained ferruginous sandstone, slightly Oolitic in structure, and containing a few fossils, marking the close of the Middle oolitic period.

In the north of England the contemporaneous bed is a calcareous deposit, also containing corals, but (as at Malton, in Yorkshire) including a considerable proportion of the fossil remains of shells, both bivalves and univalves. The bed never loses its coralline character, and may, perhaps, represent an imperfect coral reef, once extending from the south-west of England to what is now the right bank of the Humber.

Fig. 192.

Astarte elegans (Coral rag).

823. The *Oxford clay* is a very important member of the Oolitic series, attaining a thickness of not less than 500 feet, and spreading over a great part of England, more especially occupying the fen-districts in the counties of Cambridge and Lincoln, which appear to be partly caused by the union of this bed with the Kimmeridge clay, producing a wide expanse of flat and undrained country. The same deposits are well seen at Weymouth, and they cover an important part of the East Riding of Yorkshire. The stratification throughout is nearly horizontal and undisturbed, being conformable with that of the formations immediately above and below it.

The appearance of the Oxford clay is that of a stiff pale blue argillaceous bed, containing a large proportion of calcareous matter, and a more or less abundant mixture of iron pyrites. Numerous organic remains are found in it, which are sometimes preserved in the clay itself, but more frequently form a nucleus, about which iron pyrites have aggregated. Those preserved in the clay have been generally found in a very rotten condition.

824. Although the Oxford clay in many places rests immediately on the Cornbrash, and thus forms the basis of the Middle oolitic system, this is not always the case, and there is often an intervening stratum composed of calcareous sandstone abounding in organic remains, and sometimes entirely made up of them. This bed is called the Kelloway rock, or Kelloway's rock, and its thickness varies from three to five feet.

825. In the north of Scotland in various places, and in some of the Western islands, small patches of Oolitic rocks have been traced referable to this part of the period.

826. In Normandy the "Argile de Dives" is the true representative of the Oxford clay, but in Switzerland the Middle oolites depart more widely from the type of Western Europe. They are based upon argillaceous limestone (Kelloway's Rock?), and the most important strata of which they are composed consist first, of an Oolitic ore of iron, occurring in beds of marl and constituting about a third of the whole thickness of the group, and, secondly, of a bed called the Nerinæan limestone, corresponding to the Coral rag of our country.

Of these beds the one containing the iron ore is worthy of remark

from its economic importance, and it has been much worked for a long period. The Nerinæan limestone is also an interesting bed, and is so called from a somewhat remarkable fossil with which it abounds (*Nerinœa*, a genus of univalve shells closely resembling, in external form, the Turritella and Cerithium), and which is also found not only in the Coral-rag but in the inferior Oolite in England. (See fig. 155.) The Oxford clay is represented in the south of Russia.

827. THE LOWER OOLITES.—This extensive series admits of considerable subdivision in the British Islands, but the details seem to be rather of local than general interest, and though partially extending to Normandy, are by no means universal in other parts of Europe. The subdivisions are given in tabular form at the end of the last chapter, but we must now describe them a little more at length.

828. *The Cornbrash* (the uppermost bed) consists of a variable thickness of clays and sandstones, which ultimately pass into a thin rubbly stone, tough and occasionally crystalline, capping the escarpment of the Lower oolites, but frequently absent, or appearing only as an imperfect outlier. Its name is probably derived from the excellence of the corn land which results from the decomposition of the limestones, and their mixture with the sandstones and clay.

829. *The Forest marble* comes next in order. It consists of carbonate of lime, sometimes crystalline, and sometimes marly, including about 25 feet of workable stone. Organic remains occur in it in such abundance as often to make up the whole substance of the stone. It is replaced in the north of England by sandstones and shales, which are sometimes carbonaceous. The "Calcaire à polypiers" of Normandy is a coralline bed of the same age.

830. *The Great oolite* consists of a variable series of coarse shelly limestones, alternating with beds of fine soft freestone devoid of fossils, and admirably adapted for building purposes. The upper beds afford a number of alternations of hard and coarse limestones, of a yellowish-white colour and highly fossiliferous, some of which supply good building material. Below these are shelly limestones and coarse freestone; and upon them rests the well known "Bath oolite." The lowermost strata are fine-grained, scarcely Oolitic, and almost crystalline in their structure.

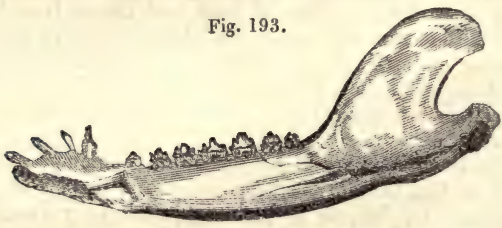
831. *The Bradford clay* is nearly of the same age as the Great oolite, and is often the only representative of this part of the series. It consists, usually, of a pale greyish clay, containing a small proportion of calcareous matter, and enclosing thin slabs of tough brownish limestone. Its thickness appears never to exceed sixty feet; it is often entirely absent, and at other times is so obscurely interstratified with the underlying Fuller's earth, or the overlying Forest marble, as to be scarcely recognisable.

The Bradford clay is particularly remarkable amongst the Oolites for the abundance in it of a peculiar fossil, the *Apiocrinite*, whose remains are usually found in groups, the stems of the Encrinites being attached to the thin bands of limestone interstratified with the clays.

832. In Yorkshire this part of the series consists of nodules of ironstone over-lying hard blue and fine-grained limestone, the whole series being non-fossiliferous, with the exception of fragments of bone and the shells of marine mollusca, around which the iron-stone nodules have formed. The hard limestones are extremely durable, and have been found well adapted for various economical purposes: more especially for works exposed to the beating of the waves, where smoothness of surface is not required.

833. The Great oolite is separated from the Inferior oolite by a series of marly beds, containing amongst them a particular kind of clay used in the manufacture of cloth, and called "*Fuller's earth*," and also a thin bed of calcareous flag-stone, known as the "*Stonesfield slate*." The former stratum, the Fuller's earth, is chiefly found at Odd Down, and on the side of Midford Hill near Bath; but it forms only a small and unimportant member (geologically speaking) of the argillaceous deposit beneath the Great oolite. The Stonesfield slate occurs in two beds, separated by a loose calcareous sandstone, and is chiefly worked for flagstones and tiles, in quarries dug near the village of Stonesfield in Oxfordshire. It has long been celebrated for the singular nature of the organic remains found imbedded in the fissile limestones which compose it, and beds somewhat similar, and also fossiliferous, occur also at Colley Weston, a village near Stamford in Northamptonshire. These latter, however, probably belong to a higher part of the Oolitic series. The most remarkable of the Stonesfield fossils are the remains of marsupial quadrupeds, part of one of which is shown in the annexed cut (fig. 193).

Fig. 193.



Jaw of Phascolotherium (Stonesfield slate).

834. The *Inferior oolite* includes a thickness of about 40 or 50 feet of freestone, forming the last of the series of the Oolitic limestones, and occasionally employed to a great extent as building ma-

terial. In the north of England, however, these calcareous beds are not present, and we find them replaced by sandstones and ironstone.

The proper base of the Oolitic system in the west and south of England seems to consist of a slightly micaceous yellow sand, often friable and incoherent, and slightly calcareous.

835. Of the lower members of the Oolitic system the Great oolite is the most important, both in thickness and practical utility. It is also the most interesting, for it contains a series of fossil shells (chiefly found near Minchinhampton), perhaps the most extensive that has yet been determined from any single bed in the Secondary period. The Inferior oolite, at Dundry, Bridport, and Leckhampton, also exhibits a rich and extensive series of fossil shells of extreme beauty, and in the most perfect preservation; but these, as well as the former, are for the most part still undescribed.

Fig. 197.

Fig. 196.

Fig. 195.

Fig. 194.

Group of Fossils from the Great oolite.
Fig. 194. Terebratula globata.
,, 195. Turbo costarius.
,, 196. Pleurotomaria conoidea.
,, 197. Ammonites striatulus.

The annexed diagram (figs. 194—197) represents some of the species of univalve and bivalve shells common and characteristic in this part of the series.

836. The representative of the Lower oolites in France is the *Caen limestone*, which is of a well known pale creamy colour, and has considerable range. It forms extensive plains in Normandy: it

lies nearly horizontal, and is often exhibited in section on the banks of rivers, from which it is worked in numerous horizontal galleries. Associated with the limestone there is found silex, chiefly in the form of black or yellowish flints, which are occasionally stratified, as in chalk, but sometimes disseminated through the mass: in the upper part of the group fossils are extremely abundant, and a very considerable number of interesting organic remains of fishes and reptiles occur in the lower beds, which probably correspond with our Stonesfield slate. The building stone is of admirable quality, soft in the quarry, of a delicate uniform cream colour, and extreme fineness of texture. It hardens by exposure, though not till after some years, and has been very much used for many centuries, not only for the churches and public buildings of Normandy and the north of France, but also in other countries to which it is still exported in large quantities. Below the limestone are three or four feet of yellowish irony calcareous grit, very fossiliferous, and representing the Inferior oolite of England.

The Lower oolites are represented in Germany and also in Russia, and probably in the Caucasus. The greater part of the Alpine chain is of the same date; but in these cases the true Oolitic character is generally absent.

837. In India, and especially in the north-western part of the peninsula, there occur beds which appear to belong to the Oolitic period. They include in Cutch several beds of coal. It is not impossible that other beds of the same age may be met with further in the east of Asia.

838. America appears to contain hardly any beds belonging to the newer part of the Oolitic period, but the older part is well represented in North America in very interesting coal-bearing strata near Richmond, Virginia, situated in a basin in altered and crystalline rocks, and containing many Oolitic fossils. The length of this coal-field is about 26 miles, and its length varies from 4 to 12 miles The beds consist of quartzose sandstones and coarse grit, the coal being in the lower part. The coal is divided into two or three seams, one of which is as much as 30 or 40 feet thick, but the thickness is very irregular. This subject will be again adverted to at the close of the present chapter (§ 868).

South America contains Oolitic deposits, but it is still doubtful to what part of the series they may be referred. They contain some fossils of considerable interest.

5. *The Liassic system.*

839. The Lias of England consists of strata in which an argillaceous character predominates throughout, but which are also remarkable for a quantity of calcareous matter mingled with the clay, and

forming occasional bands of argillaceous limestone. A few beds of sand also alternate with the clay and marl, and are sometimes mixed with the latter, forming a marly sandstone of a white or greenish colour.

Considered as a formation, the Lias in England may be traced in a north-easterly direction from Lyme Regis on the coast of Dorsetshire, where it is displayed along a line of cliffs extending for about four miles, to the coast of Yorkshire near Whitby. It consists throughout of the same beds of marly limestone, and from Gloucester northwards is remarkably regular, presenting an average and nearly uniform breadth of about six miles, being covered up on the east by the escarpment of the Oolites, and the New red sandstone coming out from beneath it on the west. Its thickness is about 600 feet; it is little disturbed, and has a regular dip, being conformable to the underlying and overlying strata, except where it comes in contact with the Carboniferous limestone in Glamorganshire and Somersetshire. It is also partially affected by the faults and disturbances of those districts.

The Lias forms for the most part broad and level plains at the foot of the Oolitic hills, only a slight escarpment being visible in the southern counties, although this becomes more prominent on the borders of Nottinghamshire and Leicestershire, where it forms a well-marked range, known as the Wold hills. It also occurs occasionally on the brow of tolerably steep escarpments in the Mendip hills; but its maximum of elevation falls short of 500 feet above the level of the sea.

840. The subdivisions of the Lias are different in different parts of England; but on the whole there seem to be four principal members.

The Upper lias, or Alum shale, is best seen at Whitby, and on the Yorkshire coast, and it attains there a considerable thickness. It consists of three distinct parts: the lower division including soft shales, extremely fossiliferous, which are separated from the uppermost series, also composed of incoherent slaty beds, by an intermediate stratum of hard shale, about 30 feet thick, containing a quantity of the mineral called *jet*, and also, occasionally, large fragments of the bituminised wood of coniferous trees. The jet itself is but a peculiar form of carbon, and there can be little doubt that it is of organic origin. It is in the upper shales of the Lias, both on the coast of Yorkshire and at Lyme Regis, that there have been found the most remarkable and interesting of those fossil remains of extinct animals, for which the formation is so celebrated. The presence of alternate bands of tolerably hard limestone and soft shale, is usually characteristic of the Lias in the different parts of England where it is most developed. The dark bluish-grey colour

united with this singular riband-like structure, is more particularly remarkable in the upper beds of the formation, and is well seen at Lyme Regis, Whitby, and Barrow-upon-Soar, in Leicestershire.

841. The principal locality of the middle beds of the Lias is the neighbourhood of Cheltenham, where the *Marlstone* of Dumbleton hill is crowded with interesting organic remains. It is made up of alternating layers of coloured clays and sands, which are occasionally calcareous, and of beds of impure limestone.

This part of the series is also represented in the north of England, where it has an average thickness of about 130 feet, and consists of sandy shales, of which the upper portions are distinguished by the presence of several bands of argillaceous irony nodules.

842. *Lower lias shale.*—The great mass of the lower division of the Lias is found in the middle of England, and consists of thick beds of dark-coloured and finely laminated shale, in which are calcareous bands and concretions. These form the base of the series, and graduate downwards into a whitish sandstone, belonging to the uppermost beds of the New red system. The transition is different again in the south of England; as at Lyme Regis marls of a light bluish colour represent the upper beds of the New red sandstone and pass into the Lias limestone by a succession of dark slaty marls, which are overlaid by a number of grey calcareous beds, and these again by other slaty marls of the upper series. The marlstone and Upper lias shales are not present in this part of the deposit in their ordinary form.

843. The lowest portion of the Liassic system occasionally consists of a very thin bed, in some places entirely made up of the fragments of fossil bodies (chiefly the remains of fish), but sometimes passing into a white micaceous sandstone, still recognisable as the same bed, although without fossils. This bed was first observed underlying a small patch of Lias, near the town of Aust (situated on the left bank of the Severn, nearly opposite the mouth of the Wye); but it has since been recognised at Axmouth, in Devonshire, and in other parts of England farther north, having a total range of upwards of 100 miles. It is rarely more than two or three inches in thickness, but invariably occupies the same geological position, and is for the most part so exclusively composed of organic remains, that a long period must have been required for its formation. In some parts of the country, and especially in Gloucestershire and Worcestershire the passage of the Lias into the

Fig. 198.

Diadema seriale.

underlying beds of New red sandstone is marked by the presence of calcareous flagstones, called Lower lias limestones; and these usually alternate with laminated shales, the whole in that case forming together the lowest deposits of Lias.

Fig. 199.

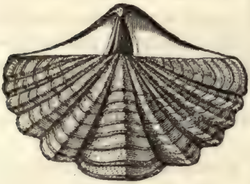


Fig. 203.

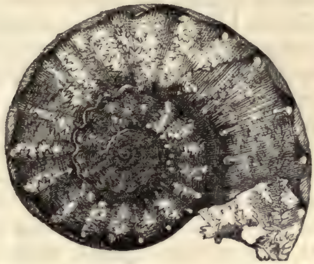


Fig. 204.

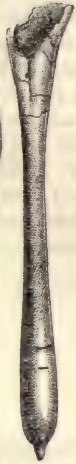


Fig. 200.

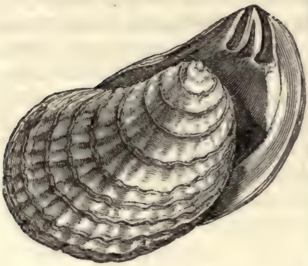
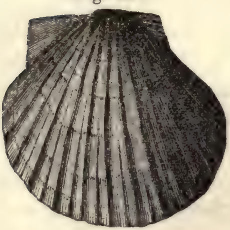


Fig. 202.

Fig. 201.



Group of Lias Fossils.

Fig. 199. Spirifer Walcoti.
,, 200. Plicatula spinosa.
,, 201. Pecten Lugdunensis.
Fig. 202. Plagiostoma giganteum.
,, 203. Ammonites catena.
,, 204. Belemnites pistiliformis.

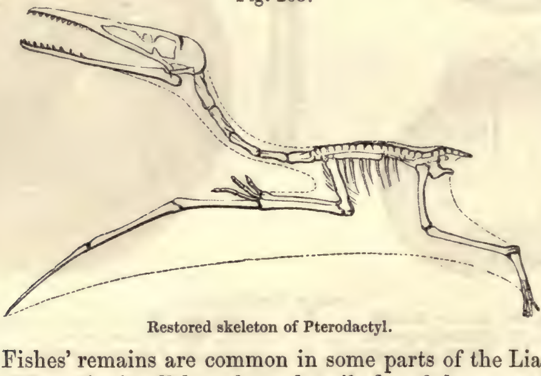
844. On the continent the Lias is frequently found, and the upper beds resemble those developed in England ; the middle, however, are usually more calcareous, and the lower more sandy, and these latter sometimes, as in Belgium, pass insensibly into the Upper new red sandstone. The town of Luxemburg is built upon a hard sandstone of this kind, and these beds pass into the rock called *Arkose,* a pecu-

liar and often metalliferous metamorphosed deposit, occurring where the Lias sands come in contact with crystalline rocks. Fossils have been found in South America, and also in northern India, attributed to the period we are now considering.

845. The Lias is a formation exceedingly rich in fossils; and amongst them are representatives of all the principal natural groups. Corals, however, are exceedingly rare and of small size. Encrinites are numerous and abundant, especially the Pentacrinite, which attached itself to floating wood. Radiated animals of other kinds characterise parts of the deposits, and of these the Diadema (fig. 198), is an example. Insects and Crustaceans have been frequently found. Star-fishes are common in the marlstone.

Both univalve and bivalve shells of various kinds are characteristic either of the whole deposit, or of different beds. The Spirifer (fig. 199) is one of the later species of a genus represented far more abundantly in more ancient deposits, while the Plicatula (fig. 200), and Plagiostoma (fig. 202), are among the ancient representatives of more recent forms. The Pecten (fig. 201), is an example of similar kind; and the Ammonite and Belemnite (figs. 203, 204) are eminently characteristic cephalopodous shells, infinitely abundant during the Lias, and scarcely less so for great part of the Oolitic period. Above 170 species of mollusca have been described from British localities only, of which as many as 70 are Ammonites.

Fig. 205.



Restored skeleton of Pterodactyl.

846. Fishes' remains are common in some parts of the Lias, and as many as 60 species in all have been described: of these many resembled the shark, but none seem to have attained very gigantic proportions. This, however, was not the case with the Reptiles, which during the period in question, were equally remarkable for their large size, voracious habits, and incredible abundance. Many species belonging to natural orders of these animals long since lost,

were then widely dispersed; and many other species existed of genera now common in distant parts of the world. The flying reptile figured in the annexed diagram (fig. 205) is a striking instance of anomalous structure. The swimming, and indeed strictly marine monsters named Ichthyosaurus and Plesiosaurus (fig. 206) are other examples,

Fig. 206.

Restored outline of Plesiosaurus.

and have been frequently described. The remains of species referred to no less than twenty-three genera of these animals have been found in England alone.

6. *The Upper new red sandstone, or Triassic system.*

847. The deposits belonging to this system are so named from the tripartite division of them observed on the continent of Europe where a calcareous rock of some importance (the *Muschelkalk*) intervenes between two arenaceous rocks called respectively *Keuper* and *Bunter-sandstone.* In England the absence of the limestone leaves no means of distinguishing between the two sands, which are only spoken of as distinct owing to the presence of some doubtful fossils, and a more marly character, combined with beds of gypsum and rock-salt, in the upper part. The British series is designated *Upper new red sandstone.*

848. It is in Cheshire, the southern part of Lancashire, and the northern part of Shropshire, which together form an extensive and rich plain, watered by the Dee, the Mersey, and the Weaver, that the uppermost beds of the New red sandstone are chiefly developed; and by a minute examination of these beds, and those of Warwickshire, the saliferous marls have been identified with the uppermost strata of the foreign Triassic system. Throughout this range the beds are nearly horizontal, the dip rarely exceeding ten or twelve degrees, and being constantly towards the east, or a few degrees north or south of that point. They are, however, affected by some important faults. The whole district abounds with salt springs, which are more especially plentiful in Cheshire; and in that county, also, there occur extensive masses of rock-salt in a solid state, their total thickness amounting to not less than sixty feet. These alternate with beds of gypsum; with numerous bands of indurated clay of a blue, red, or

brown colour; and with sandstones, frequently marly, and of a red colour.

849. The red marl district with brine springs is continued southwards into Worcestershire, and northwards into the valley of the Eden, and the same part of the formation extends also eastwards, occupying for the most part the plains through which the Humber and its tributaries make their way to the German Ocean. In Somersetshire and Devonshire similar sandstones recur, and lie unconformably, overlapping the inclined edges of the older rocks, or abutting against them, but uniformly composed of the same materials, remarkable throughout for the ochraceous colour pervading them. Between Sidmouth and Seaton in Devonshire, the red marls contain gypsum in abundance, and near Teignmouth the cliffs, which are of considerable height, consist of alternations of argillaceous beds of sandstone and of conglomerate.

850. The beds which are lowest in position of the Upper new red sandstone, are chiefly found in the middle of England, and consist of thick masses of whitish soft sandstone. In some places (as in Staffordshire) these are surmounted by conglomerates, composed of rounded pebbles of quartz rock, and other fragments, chiefly of Silurian rocks and Old red sandstone. The total thickness of this part of the formation is considerable, but has not been accurately calculated. It is only to be distinguished from the overlying saliferous marls by small differences of mineral character.

851. The whole of the Upper new red sandstone of England bears evident marks of its marine origin, even if the occurrence of so large a quantity of salt associated with it did not place the matter beyond a doubt. The almost total absence of fossils is, however, a very remarkable phenomenon, and one which is not satisfactorily accounted for, either by the prevailing sandy character of the deposit, or by the quantity of oxide of iron distributed through it. Owing to the nature of the alternating marls and gypsum of this series of strata the vegetable soil arising from its disintegration is extremely fertile; and in the greater part of the county of Devonshire, in the valley of the Severn, and yet more strikingly in the agricultural districts of Warwickshire, Worcestershire, Staffordshire, and Cheshire, many peculiarities may be observed characterising the formation.

852. The development of the Trias in France and Germany is different from that just described, and the general character of the different deposits will be seen by the following division.

The *Keuper*, the uppermost division, called by the French *marnes irisées* (variegated marls), has been identified with the upper members of the New red sandstone formation in our own country.

The group usually consists of a numerous series of mottled marls

of a red, greenish-grey, or blue colour, which pass into green marls, black slaty clays, and fine-grained sandstones. Throughout the series common rock-salt and gypsum are abundant, but the organic remains of animals are extremely rare. Of plants, however, a considerable number are preserved in some localities, and a species is represented in the annexed cut (fig. 207), where also will be found representations of two of the most characteristic fossils of the Muschelkalk, or limestone of the period.

Fig. 209.

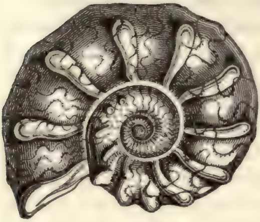


Fig. 207.

Fig. 208.

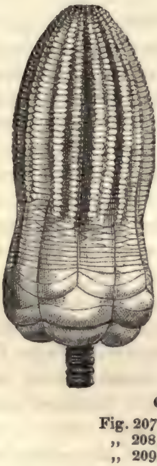


Fig. 210.

Group of Triassic fossils.

Fig. 207. Voltzia heterophylla.
,, 208. Encrinites moniliformis.
,, 209, 210. Ammonites (Ceratites) nodosus.

853. The *Muschelkalk* is a compact limestone of a grey or greenish-grey colour, and commonly contains in great abundance the remains of shells and fragments of radiated animals and fishes. It rests conformably on the underlying sandstones and either forms an escarpment, or is exhibited in a range of high table-land, such as may be seen in the north of Bavaria. The upper beds are, on the whole, more slaty than the lower ones, but still contain compact limestone

bands, characterised by the usual fossils. In the neighbourhood of Basle, and in some parts of Wurtemberg, the lower part of the formation consists of a yellowish coloured limestone, alternating with thin bands and veins of gypsum, and contains a considerable quantity of rock-salt, differing in this respect from the contemporaneous formations in other districts. Lastly, the muschelkalk is occasionally a bituminous rock, and emits a fetid, disagreeable odour when rubbed or struck with a hammer.

854. Among the remarkable fossils of this rock are remains of an animal whose footmarks are found in the New red sandstones of England and Germany, and which has been called *Labyrinthodon*

Fig. 211.

Restored outline of Labyrinthodon.

(fig. 211). From the form of the footmarks, which resemble those of the human hand, the animal has also been called *Chirotherium* (*cheir* a hand, *therium* an animal). Many species of fishes, as well as shells and some other reptiles, appear to have characterised this part of the period.

855. The *Grès Bigarré*, or *Bunter Sandstein*, is a fine-grained solid sandstone, sometimes white, but more frequently of a red, blue, or greenish tint. The structure of the lower part is tolerably close-grained, and sufficiently compact to form a good building stone; but the uppermost strata are fissile and incoherent, and pass into an earthy clay containing gypsum. The intermediate portion is compact, like the lower, but its structure is that of a conglomerate, and it is used for making millstones. In many districts the Bunter Sandstein contains numerous remains of fossil plants, and also of marine shells; but the latter are rare and confined to particular localities.

The sandstones and marls of this part of the series are spread over an extensive tract of land in Western Europe, more particularly in France, and in South-western and Central Germany. They are found in France, on the flanks of the Vosges mountains, where they overlie the Lower new red sandstone (there called "*grès de Vosges*"), and again in several parts of Central France, and in the Sub-Pyrenees.

856. The whole series of the Secondary rocks may be regarded as having been deposited in open seas, which were in some places deep, in others shallow, and generally dotted over with islands. No continuous land forming continental masses seems to have prevailed in any extensive districts in which rocks of this age are now observed, but abundant evidence exists of the near vicinity of considerable islands, some of them probably, especially near the present lower Oolite deposits of England, having considerable mountain ranges.

857. The crystalline rocks of the Secondary period are neither few nor unimportant. On the north coast of Ireland, and in the southernmost of the western Islands of Scotland, large quantities of basalt have been poured out, producing a marked effect upon the chalk, and probably erupted during the period immediately succeeding the deposit of that bed. In the New red sandstone of England there are numerous localities where the older rocks have been forced through, and some where the sandstone rocks are penetrated by dykes of crystalline rock, resembling granite and Syenite. The granites and slates of Charnwood Forest in Leicestershire, must be of early Secondary origin, and many of the highly altered rocks of the Alps may safely be referred to the period. It is not unlikely that the date of change of the metamorphic schists and the porphyries of the great mountain chains of Central Asia and the two Americas, are also Secondary. So far as England and Europe are concerned there is, however, reason to suppose that the whole Secondary epoch was marked by almost continuous depression.

858. The elevations of this period, according to M. Elie de Beaumont, were four. The first took place between the deposit of the Lower new red sandstone and the Trias, and is considered to have had a direction S. 21°, W. and N. 21°, E., or nearly that of the Western Alps already described (§ 779). It is called the system of the Rhine, and is marked by the cliffs on the borders of the Rhine between Basle and Mayence.

859. The next system is that of the Thuringian forest, and runs W. 40°, N. and E. 40°, S. It is seen in the chain of mountains from which it is named, and which extend also into the Böhmerwald, forming the natural frontier of Bohemia and Bavaria. In France it is marked in the south-west part of the Vosges mountains and in the west of the same country in Brittany. It is supposed to have taken place between the Triassic and Oolitic periods.

860. The third elevation is that of the Côte d'Or, nearly at right angles to the former, and running W. 40°, S. and E. 40°, N. It is extremely well-marked in France and in the Erzgebirge, and seen also in the cliffs of the Vicentin. It is of the age between the deposit of the Oolites and the commencement of the Lower greensand.

861. The fourth and last system of this period is that of the Monte

Viso, seen in the Alps of Dauphigny. It runs N.N.W. and S.S.E., being nearly coincident with that of Tenare — the most modern system of elevation, and one already described in a former paragraph (§ 781). The disturbances of this part of the period are supposed to have taken place between the deposit of the two principal divisions of the Cretaceous series. This last of the great systems of the Secondary period is supposed to have determined the principal direction of the shores of Italy, and some of the principal mountain ridges of Greece.

862. "The distribution of the oceans during the Secondary epoch cannot be very definitely or surely discerned; but enough is clear to reveal a condition of things still more remote in character than that of the Tertiary epoch from what is in existence now. The Tertiary seas, whose extent has been already described, were, during this older period, in close and free communication with each other; for the elevation of the Secondary rocks, especially in the old continent, tending to narrow all their shallow channels, diminished the number of their points of contact, and still more—their extent. The formation and upheaval of all the rocks of this group evolved this result; but perhaps their operation is most easily seen in the case of the jurassic and the cretaceous beds. The lower members of the Secondary group defined the contours of many basins in Central Europe—on the banks, for instance, of the Rhine; between the Harz, the Erzgebirge, and the Thuringian forest; in England, Poland, Russia, &c. They also separated the great Siberian basin from the seas of Europe, and probably diminished the magnitude of the Chinese inland seas. Humboldt found them in the valley of the Orinoco, and Schomburgk in the interior of the crystalline district of Guayana. By the jurassic formation, on the other hand, distinct walls of separation were established in France, Switzerland, in the south-west of Germany, in Northern Hungary, Spain, and the north of Africa; and new shapes were imposed on the basins of Siberia, China, and Central Asia. Thus emerged the cretaceous masses, completing everywhere the contours of the Tertiary basins, particularly in three South European peninsulas; at the same time isolating Sahara from the Mediterranean, forming boundaries to Arabia, Mesopotamia and Southern Persia, the coast of Tranquebar, the centre and north-east of Asia; perhaps China and Borneo, as well as Australia. They are likewise found on the two slopes of the Alleghanies, on the south-east slope of the Rocky Mountains, in several parts of Mexico and Colombia, and among the Andes of Peru and Chili."*

* Johnston's Physical Atlas, *ante cit.*

Note on the coal-fields of the Secondary epoch.

863. In addition to the various valuable materials obtained from the Oolitic and other Secondary deposits already noticed, there are also found in it bands of coal, lignite, and other mineral fuel, sufficiently important in some districts to be worthy of more than passing notice. These are, indeed, of comparatively little value in England, where the rocks of the older or Palæozoic epoch are so much more rich in similar deposits, but elsewhere they form important sources of mineral wealth. We shall, therefore, offer here a few remarks on the Kimmeridge coal, the Brora coal, the Oolitic coal-field of Yorkshire, the coal-fields of Cutch in India, of the same geological age, and lastly, the Richmond coal-field of Eastern Virginia, in the United States of North America. Corresponding deposits, also Secondary, but of inferior importance, are found in Piedmont, Lombardy, the Alps, France, and Silesia, and also in the Andes.

864. The Kimmeridge coal is nothing more than a highly bituminous shale of rather high specific gravity (SG=1·319). It is of dark-brown colour, and without lustre, effervesces slightly with acids, contains no iron pyrites, and burns readily with a yellowish, rather smoky, and heavy flame. It has been used for pottery and other purposes, but is not much worked at present. Its position is in the Kimmeridge clay. It is of very little value, and does not extend widely.

865. The Brora coal is of doubtful geological age, but has been generally considered as more nearly allied to the lower than to the upper part of the Oolitic series. It has been mined for more than 250 years, and appears to consist of two workable, and several smaller seams, the main seam being 3½ feet thick, and worked in one pit at a depth of 250 and in another at 338 feet. The quality of the coal is bituminous, it has a cubical fracture, and burns to a white ash. The total quantity is not large, but upwards of 70,000 tons were obtained from one pit between the years 1814 and 1826.

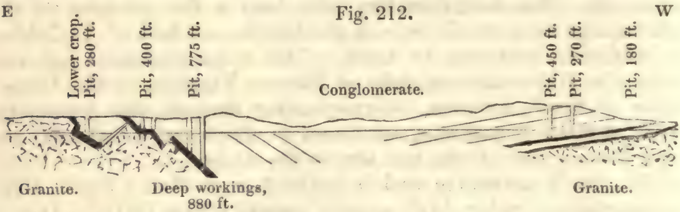
866. The Yorkshire Oolitic coal-field contains only a few thin seams of carbonaceous matter, of very irregular quality, but has been worked for more than a century, and has yielded a good deal of coal. The beds overlie the Lias near Whitby, and have been traced to some distance in the interior, the area being estimated at about 100,000 acres. Some parts of the deposit contain a coal which burns freely, with comparatively little ash; but the greater portion can only be used for inferior purposes.

867. In India there are several coal-fields of moderate dimensions all of them very imperfectly developed, but belonging, it would seem, to the Secondary epoch. The most distinctly known is an area of about 200 miles in length, averaging 20 miles in breadth

in the north side of the Gulf of Cutch. The formation consists of sandstone and shale, with bands of iron ore and seams of coal, which do not exceed 18 inches in thickness. The quality of the coal is described as good; it ignites quickly, and burns with a bright flame.

868. By far the most important, if not the only really important beds of coal of the Secondary period, are those of Richmond, Eastern Virginia, United States, of which a section is represented in the annexed diagram. The whole productive area has been estimated at

Fig. 212.



Section of the Bituminous Coal-field, Richmond, Eastern Virginia, U.S.

about 185 square miles, but the depth, except at the outskirts, is not known. The coal occurs at the base of a large series of granitoid sandstones, called psammite, and reposes almost directly on granite. The whole of the central area is covered by conglomerates. The number of coal-seams is at least three, the uppermost being the most important; the total thickness of coal varying from 11 to 40 feet, according to the inequalities of the floor. The quality of the coal is bituminous and good. It has been long and extensively worked, Philadelphia alone taking 10,000 tons annually, and it is found valuable in the manufacture of gas. Several accidents have happened in working it from explosions of the gas. Some of the mines contain water, but others are dry.

869. "The coal of Eastern Virginia, although derived from a different vegetation from that of the ancient carboniferous period, resembles very closely the older coal in structure, appearance, and composition. That of the Blackheath mine has usually a highly resinous lustre and conchoidal fracture, and always contains at least as large a proportion of gaseous or volatile ingredients (hydrogen, oxygen, and nitrogen) as the coal of the palæozoic rocks of the United States.

"The coal is also divided into horizontal layers of slight thickness parallel to the planes of stratification, as in the older kinds of coal. Sometimes these layers consist alternately of highly crystalline and resinous coal with a bright lustre, and of other portions exactly resembling charcoal in appearance."

The following is an analysis by T. H. Henry, Esq., of the Richmond coal, dried at 250° Fahr.:—Moisture 1 to 1½ per cent; Carbon 80·38; Hydrogen 4·08; Oxygen and Nitrogen 6·19; Ash 9·35.*

* Lyell on the Coal-fields of Eastern Virginia. Quart. Geol. Journ. vol. iii. p. 261.

CHAPTER XVI.

ON THE ROCKS AND FOSSILS OF THE NEWER PORTION OF THE PALÆOZOIC EPOCH.

870. The older of the three great epochs which have been assumed by geologists is understood to include a large number of very distinct deposits, many of them exceedingly thick, and for the most part traceable over wide areas by rocks marked with very similar geological and mineralogical characters. The series may be grouped into about five parts, of which the two of newest date are called Upper or newer, and the two of oldest date, Lower or older. The term *Palæozoic* being applied to the epoch generally, marks the relative antiquity of the period taken as a whole. The following are the five principal subdivisions :—

NEWER PALÆOZOIC	1. MAGNESIAN LIMESTONE, OF PERMIAN SYSTEM. 2. CARBONIFEROUS SYSTEM.
MIDDLE PALÆOZOIC	3. DEVONIAN, OF OLD RED SANDSTONE SYSTEM.
NEWER PALÆOZOIC	4. UPPER SILURIAN SERIES. 5. LOWER SILURIAN SERIES.

1. *The Magnesian limestone or Permian system.*

871. The rocks which immediately underlie those of the Triassic or Upper or new sandstone series of England, offer a close resemblance to the latter in mineral character, but are covered unconformably by them. Elsewhere, however, and especially in Russia, a large group of deposits of this date exists, and is marked by distinct peculiarities. The abundance of carbonate of magnesia is a characteristic feature of part of the series, and thus the name "magnesian limestone" has been generally applied to designate the group.

872. The following are the chief sub-divisions of the system :—

1. *Magnesian limestone series.*

ENGLAND.	GERMANY.	
Grey thin-bedded limestone. Red marl and Gypsum. Magnesian limestone and magnesian conglomerate.	Zechstein.	Letten. Stinkstein. Rauwacké.
	Shaly beds.	Argillaceous schist. Bituminous schist. Arenaceous schist.

2. *Lower new red sandstone series.*

Marly beds, with thin bands of compact and shelly limestone. Lower new red sandstone.	Rothe-todte-liegende.

873. The *Magnesian limestone,* and the beds associated with it, rest immediately on the upper strata of the carboniferous system, and may be traced from Nottingham to the mouth of the Tyne continuously, but not rising to a high level, except in part of the county of Durham, where they are cut off by the coast line. The rock, being for the most part easily disintegrated, has suffered much from denudation, and several outliers, or portions of the strata completely isolated from the principal mass, are seen from point to point beyond the edge of the formation.

874. The uppermost beds of the series, which overlie the true magnesian limestone, consist of gypseous marls of variable thickness, and sometimes occupy the base of a low escarpment, formed by a grey, thin-bedded limestone (the highest bed of the series), which dips into the plain of the New red sandstone. The thinness of the uppermost beds is characteristic, and they often pass into mere laminæ, with plates of marl interposed between them. Organic remains are not common, and when they do appear, they are obscure.

875. The deposit of magnesian limestone which comes next in order, occupies by far the greater part of the escarpment overhanging the coal-measures. It is extremely complicated in its structure, presenting more varieties in the arrangement of its subordinate parts than any newer formation. Considered, however, generally, the lower part is usually of an open arenaceous texture, and of red colour, being made up of a congeries of small crystals, coated with oxide of iron. The crystals, loosely thrown together, as it were, in the lower beds, occasionally become more closely packed and of paler colour, and a little higher in the series form a tolerably compact rock, and sometimes a stone of such close grain as to be much used for troughs and cisterns. The magnesian limestone in this state is called *Dolomite,* and the crystalline or semi-crystalline structure of the mineral is usually predominant, although in some quarries a compact form of it is seen, associated with thin beds of crystalline rock of loose texture, of the same kind as those described above. The compact dolomite has a flat conchoidal fracture, and is translucent at the edges; but it is very irregular in structure, and passes by insensible gradations into other varieties. Some account of those masses of dolomite capable of being used for buildings and other economical purposes will be found in a previous chapter (Chapter XI. § 544), where also analyses of magnesian limestones are given and compared with the composition of other limestones.

876. The magnesian limestone occasionally puts on other and very different forms: at one time, for instance, we find it made up of laminæ parallel to the plane of stratification; at another, of earthy masses, which are sometimes hard and regularly bedded, and sometimes unstratified. A remarkable peculiarity of structure in this

bed has sometimes also obliterated the lines of deposition so that a section of the rock exhibits a mass of crystalline, compact, cellular, and earthy materials rudely blended together, and passing into each other without order or arrangement.

877. But in the apparent confusion thus produced the minute grains which enter into the composition of the rock are occasionally well defined and of spheroidal shape. The mass, in such a case, appears Oolitic, and there are several localities in the southern part of Yorkshire where Oolitic magnesian limestone is worked as a freestone, and resembles not a little the building stone obtained near Bath from the Secondary rocks. Like this latter stone it cuts readily in the quarry, and hardens on exposure to the atmosphere; but the grains are less uniform in size, possess a glimmering lustre, and are hollow and made up of concentric laminæ.

878. Turning now to the magnesian limestone as exhibited in the south of England, we shall find the New red sandstone of Bristol succeeded by a dolomitic conglomerate, made up of angular or slightly worn fragments of an underlying limestone, cemented by a red or yellow magnesian paste.

This deposit fills up the hollows and irregularities of the lower and older rock, and may be seen in the precipitous cliffs on the Avon. It is undoubtedly the representative of the magnesian limestone of the north of England.

879. The magnesian limestone series may be traced in the north of France and in Burgundy, but is most fully developed at Mansfeld in the Thuringian forest, in the district of the Hartz, and in Franconia. Throughout the south of France it appears to have no representative, and is most likely altogether absent. When most perfectly expanded, the whole series is divisible into two groups, the lower one for the most part argillaceous, and the upper calcareous, and the series then rests immediately upon the conglomerates of the *Rothe-todte-liegende*.

880. The upper or calcareous portion in Germany is called *Zechstein*, and is chiefly a compact limestone, but the highest beds are marly, consisting of, 1st, a greyish, bluish, or greenish clay, called *Letten*, often containing rolled fragments of dolomite and crystals of gypsum. This reposes on (2) a fetid limestone called *Stinkstein*, which is a compact or granulated rock, of a blackish-brown or greenish colour, and extremely bituminous, giving out an offensive odour when struck or rubbed. The lower bed (3) of the Zechstein is called *Rauwacké*, and consists of a hard but cellular magnesian limestone, abounding in long, irregular, and narrow cavities, which are most numerous when the bed attains a considerable thickness, but are almost obliterated in the thinner and more compact portions. The whole thickness of the Zechstein is rarely more than 20 or 30 yards.

881. In the zechstein and the beds associated with it, there are found occasionally several minerals, amongst which may be enumerated white crystallized carbonate of lime, crystallized sulphate of lime or gypsum, quartz, and mica. Both the sulphuret and carbonate of copper, also, occur together with galena in mineral veins traversing the formation.

882. Of the schistose beds which form the base of the magnesian limestone series, the lowest is sandy, and forms a kind of transition from the underlying sandstones. It is of no great thickness, and is succeeded by a bituminous band, remarkable for great uniformity both of mineral character and fossil contents, being traceable over a considerable district in Germany, and forming an excellent geological horizon for an extent of, at least, 250 miles. According to M. D'Aubuisson, one-tenth part of the mass of this bed consists of bitumen and carbon: and, although not more than a foot in thickness, it contains so considerable a quantity of iron and argentiferous copper pyrites as to be worth working as an ore, whence it has received the name of *Kupfer-schiefer*, or copper slate.

This bituminous schist is also remarkable as containing, in great abundance, the nearly perfect fossil remains of a large number of extinct species of fish. By means of these the bed has been identified with the contemporaneous formations in other countries; and as the remains of reptiles have also been discovered, associated with the fragments of fish, the Kupfer-schiefer is thus brought into relation with the Bristol dolomitic conglomerate, as well as with the Magnesian limestone of Durham and the Permian System of Russia.

883. The fossils of this part of the series are more abundant than those of the lower bed though still comparatively rare, and the beds are poorly provided, not only in species but individuals. On the whole, however, these remains mark a condition of things more closely resembling that of the other Palæozoic deposits than those of the Secondary period.

Fig. 213.

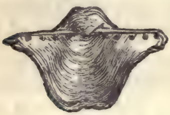
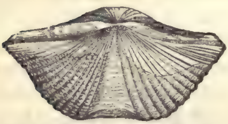


Fig. 214.



Magnesian Limestone Fossils.
Fig. 213. Productus aculeatus.
214. Spirifer undulatus.

The annexed figures of Brachiopodous shells, (fig. 213, 214) are characteristic of the magnesian limestone, and with them occur several fragments of fishes and some reptilian remains of much interest. The whole number of species determined when Sir R. Murchison first proposed the name Permian from the Russian equivalents of the series, was 166: and although many have since been added, they do not alter the general character of the fauna, which presents a remarkable preponderance of fishes' remains.

884. The upper members of the Permian system are far more interesting than the lower portion; but it has not yet been very clearly determined what is the cause of the presence of so large a quantity of carbonate of magnesia in these deposits, while this mineral is elsewhere so rare. Perhaps the best suggestion is that lately made by Dr. Forchammer, who attributes the dolomination or

infiltration of carbonate of magnesia to numerous springs containing that mineral poured out during or subsequently to the deposition of the carbonates of lime which form the base of the whole deposit.

885. The lowest bed of the magnesian limestone group is called from its lithological character and relative geological position "the Lower new red sandstone;" but it might very fairly be associated with the Upper coal-measures, for it contains numerous remains of extinct vegetables not to be distinguished from species found throughout the carboniferous system. It differs somewhat, however, from the coal grits in mineral composition, being more discoloured with oxide of iron, besides being chiefly made up of a conglomerate in which quartz and decomposed granite abound. This conglomerate, although in its lower portion exceedingly coarse, passes upwards into a fine-grained sandstone, and so by finer sands mixed with marl shows a gradual transition to the upper and marly beds. Beds of freestone are sometimes, but rarely, found alternating with the fine sands and clays of this division; and the mass is altogether very irregular both in thickness and extent, appearing to have presented an uneven surface at the commencement of the deposit of the more recent magnesian limestones, and in some places to have undergone considerable degradation before those beds were superimposed. The irregularity thus described as affecting the lower strata must have been owing, in all probability, to subterranean movements disturbing the bed of the ocean during the period of their deposition. The marls associated with the fossiliferous bands in the county of Durham, are also sometimes bituminous, and traces of bitumen occur in thin-bedded compact limestones of the same geological date.

886. The Lower new red sandstone, or *Rothe-todte-liegende,* as observed in Germany, is perfectly similar, in almost all respects, to the contemporaneous beds in our own country, being made up of coarse conglomerates, alternating with marls and shaly beds, the conglomerates being generally composed of fragments of the neighbouring crystalline rocks, cemented by a fine ferruginous, and sometimes argillaceous sandstone.

887. In France this deposit is exhibited wrapping round the old rocks which form the central axis of the Vosges. It consists of a coarse incoherent sandstone, generally of a red but sometimes of a bluish-grey colour, alternating with shaly and micaceous marls, the whole formation being extremely variable, both in its mineral character and in the extent of its development. It passes insensibly into the upper beds called the "*grès des Vosges,*" or Vosges sandstone, there being no intermediate bed of magnesian limestone.

888. The Permian system of Russia exactly corresponds to the Magnesian limestone and Lower new red sandstone of our own country; but it has been judged advisable to give a distinct name

to the continental group, and the district in which the rocks are most perfectly exhibited being included in the ancient kingdom of Permia, that name has been selected, for reasons similar to those which had induced Sir R. Murchison, on a former occasion, to apply the term "Silurian formation" to a group typically exhibited in the region of the ancient Siluri.

The Permian district extends for about 700 miles from north to south along the western or European flanks of the Ural chain, and for nearly 400 miles between those mountains and the river Volga. The strata within this area are described as lying in an enormous trough of carboniferous limestone, and, although occasionally thrown into anticlinal axes of some length, are often traceable for great distances, without any break or interruption of the sequence.

889. The Permian rocks of Russia consist of a great number of distinct strata of very varied lithological character. They are composed, for the most part, of white limestone with gypsum and rock salt, of red and green gritstones with shales and occasionally copper ore, and of magnesian limestones, marlstones, conglomerates, &c. The whole series is fossiliferous, and contains the remains of extinct species of animals and vegetables, greatly resembling those of the Carboniferous period. In the Russian beds, also, there have been discovered reptilian remains like those of the Bristol magnesian conglomerate, and fish identical with the species from Durham and from Mansfeld in the Thuringian forest.

2. *The Carboniferous system.*

890. The deposits associated under this name include some of the most important accumulations of mineral wealth met with in the earth's crust, and they require, therefore, careful and somewhat detailed notice. There are three principal divisions, designated as follows, and we proceed at once to the consideration of these.

1. Coal measures.
2. Millstone grit.
3. Carboniferous limestone.

As developed in England, the Carboniferous system consists of an extended series of highly fossiliferous limestones, alternating with sandstones and shales, the latter frequently containing a large number of the remains of vegetables, which in some cases are so abundant as to form valuable seams of coal. The relative position of the different rocks with respect to the coal is not constant. The presence of carbon is the characteristic feature both in the upper and lower divisions; and throughout the whole series there occur at intervals bands of carbonaceous matter only occasionally of importance as coal, but sufficiently indicative of the vicinity of land clothed with vegetation.

891. *The Coal-measures.* — This large and interesting group of deposits, remarkable for containing vegetable matter in an almost crystalline state, frequently extracted for the purpose of fuel, and obtained from various parts of our own and other countries, demands our first attention. It may be described generally as offering a repeated succession of argillaceous and sandy bands, the former generally laminated and called *shales*, and both coloured with iron and carbon :— the whole alternating with bands of nearly pure carbon, varying in thickness from a fraction of an inch to 30 or 40 feet, or even much more, and amounting sometimes in number to much more than 100,—crowded throughout with fossil remains of vegetables, and containing also a few shells and other indications of animals. The extent to which the whole series is developed varies much in different districts, but in South Wales has been calculated by actual sections to amount to 12,000 feet, the sandstones greatly preponderating, while in Nova Scotia there are nearly 15,000 feet of deposits, apparently of the same date, and none of them in either case exhibiting direct evidence of marine deposit.

Fig. 215.

Calamites cannæformis.

Fig. 216.

Fig. 217.

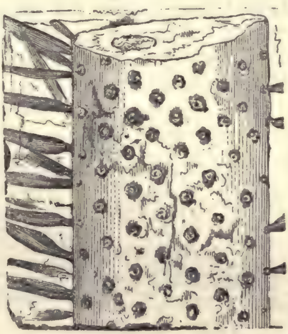


Fig. 218.

Group of fossils from the Coal-measures.
Fig. 216. Sphenopteris Hænighausi.
„ 217. Stigmaria ficoides.
„ 218. Tooth of Megalichthys Hibberti.

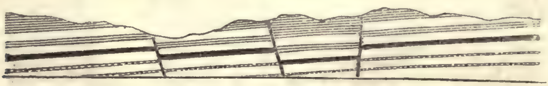
892. The uppermost part of the coal-measures generally consists of gritstones, and does not afford any large proportion of carbonaceous matter, so that where the development of the series is most

complete, as in the cases already alluded to, there are some 2,000 or 3,000 feet of the whole series chiefly arenaceous and quite unproductive of coal. These are sometimes called "upper coal grits," and are often rather barren of fossils. The middle and lower part of the series abound in remains of plants, and almost every coal band reposes on clay, containing a vast multitude of the rootlets of a tree (Stigmaria), of which some mention has been already made (§ 676). Ferns (figs. 132, 216) and reed-like plants (fig. 215) are also found in great abundance throughout these deposits, and in a remarkable fresh-water limestone near Edinburgh, considered to belong to the base of the true coal-measures, the teeth and jaws of a large and remarkable fish are often met with, and may be mentioned as characteristic of the rocks of the carboniferous period. This fish has been called *Megalichthys* (*megale* great, *ichthys* fish), and one of the teeth is represented in the diagram (fig. 218). Other fossil remains, and among them the foot-prints of reptiles, have been recognised in foreign beds of the Carboniferous period, though not yet observed in the rocks of this country.

The Megalichthys is one of those genera which may rank amongst the singular links connecting two great natural divisions, which are apparently so strongly marked, and separated from one another so widely, as to offer scarcely any points of resemblance. It combines with many of the characters of a true fish, many close and striking analogies with reptiles; and the teeth more especially, so closely resemble those of some crocodilian animals, that when first discovered they were immediately referred to that class; and not only the teeth, but the scales also seemed to indicate the same affinity.

893. The coal-fields of Great Britain are affected by many extensive and complicated faults. The way in which these influence the value of the beds may be partly understood by reference to the annexed diagram (fig. 219), where a bed of coal is represented as having been frequently removed in position, in consequence of which it can be worked at moderate depth over a distance of country which would otherwise have carried the deposit far below the surface at the rate of inclination observed.

Fig. 219.



Faults in coal-measures.

894. The coal-measures occupy definite and limited areas of somewhat considerable extent in various countries of Europe, Asia, and North America, and in many of the islands adjacent. True coal has not yet been met with in Africa or South America. We may regard the following as a rough approximation of the coal areas in the chief countries mentioned; only those being referred to which are of the

date of the coal deposits of the British Islands, or at least belonging to the Palæozoic period. To this is added a statement of the estimated annual production.

Countries.	Coal-area in square miles.	Propn. to whole area.	Annual production in tons.
British Islands	12,000	1—10	32,000,000
France	2,000	1—100	4,150,000
Belgium	520	1—22	5,000,000
Spain	4,000	1—52	550,000
Prussia	1,200	1—90	3,500,000
Bohemia	1,000	1—20	
United States of America	113,000	1—20	4,000,000
British North America	18,000	2—9	?

Table of the principal Coal-fields of the British Islands.

	Estimated workable area in acres.	Number of workable seams.	Estimated total thickness of workable coal in feet.	Thickest bed in feet.	Thickness of coal-bearing measures in feet.
1. *Northumberland & Durham District.*					
Newcastle coal-field	500,000	18	80	7	
2. *Cumberland and Westmoreland, and West Riding of Yorkshire.*					
Whitehaven and Akerton	80,000	7		8	2,000
Appleby (3 basins)	17,000				
Sebergham (Cumberland)	?	1	3	3	
Kirkby Lonsdale	2,500	4	17	9	
3. *Lancashire, Flintshire, & North Staffordshire.*					
Lancashire coal-field	380,000	75	150	10	6.000
Flintshire	120,000	5	39	9	200
Pottery, North Staffordshire	40,000	24	38	10	
Cheadle, ditto	10,000				
4. *Yorkshire, Nottinghamshire, Derbyshire.*					
Great Yorkshire coal-field	650,000	12	32	10	
Darley Moor, Derbyshire } Shirley Moor, ditto	1,500				
5. *Shropshire and Worcestershire.*					
Colebrook Dale, Shropshire	21,000	17	40		
Shrewsbury, ditto	16,000	3			
Brown Clee-hill, ditto	1,300	3			
Titterstone Clee-hill, ditto	5,000				
Lickey-hill, Worcestershire	650	?	?	?	
Bewdley ditto	45,000	?			

	Estimated workable area in acres.	Number of workable seams.	Estimated total thickness of workable coal in feet.	Thickest bed in feet.	Thickness of coal-bearing measures in feet
6. *South Staffordshire.*					
Dudley and Wolverhampton ..	65,000	11	67	40	1,000
7. *Warwickshire and Leicestershire.*					
Nuneaton	40,000	9	30	15	
Ashby-de-la-Zouch...... ...	40,000	5	33	21	
8. *Somersetshire and Gloucestershire.*					
Bristol	130,000	50	90		
Forest of Dean	36,000	17	37		
Newent (Gloucestershire)....	1,500	4	15	7	
9. *South-Welch coal-field.*	600,000	30	100	9	12,000
10. *Scottish coal-fields.*					
Clyde valley .... Lanarkshire .... South of Scotland, several small areas	1,000,000	84	200?	13	6,000
Mid-Lothian	?	24	94		4,400
East-Lothian	?	60	180	13	6,000
Kilmarnock .... Ayrshire	?	3	40	30	
Fifeshire	?	?	?	21	
Dumfries coal region	45,000	10	55	6	
11. *Irish coal-fields.*					
Ulster....................	500,000	9	40 ?	6	
Connaught	200,000				
Leinster (Kilkenny)	150,000	8	23		
Munster (several)	1,000,000				

895. It is necessary to remark that the total number of workable seams in each district is by no means clearly determined in all cases, and that many more local names of seams are frequently given than there are distinct beds. The appearance of the same seam in the same district varies often very greatly, and the thickness of strata between known beds is sometimes very different within a short distance. The total number also of workable beds in a district is very rarely obtained in the same colliery; and thus the object in the above table, which has been rather to give a good general idea than a perfectly accurate account of particular cases, must be kept in view by the reader in making any practical use of the information afforded. We have not space to allude to more than a few of the chief of these areas, and the peculiar points of geological interest in them to which attention is especially required are not very numerous.

896. *The Newcastle coal-field* is almost without ironstone, and in it the coal-measures repose on millstone grit and are covered up by magnesian limestone. They consist chiefly of sands, called *post*, often of very great thickness and far exceeding in magnitude and extent

the various beds of shale. The sandstone is especially abundant near the upper part of the series. Cannel-coal is found in the district to some extent. It contains very little bitumen. The quality of the coal-seams varies considerably, but the following account of three principal varieties may be useful.

Analyses of different kinds of Newcastle coal.

	Splint-coal.	Caking-coal, No. 1.	Caking-coal, No. 2.	Cherry-coal.
Density	1·302	1·274	1·280	1·266
Carbon	74·961	83·588	87·809	84·694
Hydrogen	6.254	5·150	5·159	5·054
Nitrogen and Oxygen	4·873	8·743	5·139	8·476
Ash	13·912	2·591	1·393	1·576
Relative heat by the same weight of coal	110·34	114·98	122·56	116·63
Relative heat by same volume of coal	108·99	111·31	119·03	112·07

In the above table, the Splint-coal is a coarse variety from a small bed of black colour and considerable hardness, at the bottom of the series. The Caking-coal, No. 1, is one of the best coals raised, and is from South Hetton. It is resinous, tender, and brilliant. The Caking-coal, No. 2, is a lower seam from Garesfield, of brilliant lustre, highly bituminous, soft, and friable. The Cherry-coal is a thin, soft, friable bed, sunk through in the Jarrow Colliery. The analyses are by Mr. Richardson, and are taken from M. Piot's "Memoire sur l'Exploitation des Mines de Houille aux environs de Newcastle-sur-Tyne," p. 13.

897. It is estimated that the mean thickness of the workable coal over the whole area of the Newcastle coal-field is about twelve feet, or four yards, and as the weight of a cubic yard of coal may be estimated at above one ton, it thus appears that there have been not less than about 10,000,000,000 tons of mineral fuel present in the whole field. It may be considered that about 5,000,000 of tons are at present removed or wasted annually, which would give a probable total duration of about 2,000 years from the commencement of the workings. It is proper, however, to deduct one eighth part as equivalent to the consumption up to the present time, and thus there would appear to remain a quantity which would admit of the present supply being obtained for 1750 years, or thereabouts. The works in the Newcastle coal-field, are carried on to a very great depth, one mine being sunk to 1,488 feet from the surface, and another at Monkwearmouth to 1,794 feet. A vast quantity of water often issues from the sinkings.

In estimating the quantity of coal in a given district it is usual and right to make a large deduction from the apparent surface area to allow for accidents of denudation, injury from faults, and also for that part of the coal thrown out of workable depth. After this is done, and the average acreage of coal obtained, we must still deduct nearly 50 per cent. for what is left underground in pillars and small coal, and the quantity required for colliery consumption or wasted. When this is done, the

quantity in tons of large saleable coal may be safely estimated as equal to the number of cube yards. The average weight of good Wallsend coal is stated at 78·945 lbs. per cubic foot, the specific gravity being 1·263. This would give 2131½ lbs. the cube yard.

898. *The Whitehaven coal-field* is separable into two divisions, the upper part containing the more valuable seams. Some of the seams are worked far under the sea; and one extensive mine has been destroyed by inundation. The coal is of good quality, burns with a clear flame, and ultimately cakes. The number of seams is considerable, but they are chiefly very thin.

899. *The Lancashire coal-field* presents a very extensive development of the coal-measures, of which three divisions have been traced, the middle containing the most valuable seams. It has been calculated that the total quantity of coal in this field amounts to 8,500,000,000 tons, and the annual consumption is about 3,500,000. Many of the seams are extremely thin; but the quality is good. The sinkings are moderately deep, and not greatly troubled with water.

The area of the Lancashire coal-field is very irregular in form, measuring about 50 miles in length and 15 in extreme breadth, reaching from Liverpool in a north-east direction to Yorkshire, and thence due south, past Manchester and beyond Macclesfield. Besides this area, which is occupied by true coal-measures, the lower beds of millstone-grit yield coal to a considerable extent, so that the area might in this way be extended to include 1000 square miles of coal-bearing strata.

The sections of this region are unequal as regards the aggregate of strata and of coal-seams. In one direction there are 75 beds of coal, each more than one foot thick, in 2000 yards of strata, having an aggregate of 150 feet of coal. Traversing another direction a second section shows 26 seams of more than a foot, containing 93 feet of coal.*

In the upper beds occurs a fresh-water limestone, worked at Ardwick, near Manchester, and containing many fossil remains. Not far from this, in geological position, there have been found many trunks of large trees standing upright on the coal-seams; and the almost invariable occurrence of stiff clay, forming a floor on which the coal rests, has been supposed to prove that vegetable matter formerly grew upon the spot where the coal is now found, although the great and sudden alterations in the thickness of the seams show that the surface was exposed to frequent changes of level. Some very considerable faults are known in the coal-field, the principal one being so extensive as to carry the coal 1000 yards below its former level.

900. *The Yorkshire coal-field* is remarkable for the great variety of coals it presents—some being very valuable, and some very poor.

* Taylor's "Statistics of Coal," p. 294.

A large quantity is worked near Sheffield, Leeds, Bradford, and Halifax, much of this being cannel-coal, admirably adapted for gas, household purposes, &c., and some pieces hard enough to be worth manufacturing into toys and ornaments. The three principal varieties are the anthracitic, soft, and cannel coals; the latter being often iridescent. The depth to which the Yorkshire seams are at present worked is not very considerable—rarely, if ever, exceeding 1000 feet.

901. *The Shropshire coal-fields.*—Of these the most interesting and important is that of Colebrook Dale, which is not less remarkable for its valuable mineral contents of coal and iron, than for the many and complicated disturbances it has undergone. The coal is of fair quality, rather heavy, and contains from 34 to 41 per cent. of volatile substances. There are several seams of clay iron-ore, and the iron made has sometimes been considered the best in England. The following is stated as the average produce of the area :—

Large coals	31,944	tons per acre.
Small coal or slack	7,986	,, ,,
Iron-stone	13,794	,, ,,

Average specific gravity of the coal .... 1·268
——————————— iron-ore .... 3·527

Thus the whole contents of the district may be stated approximately, as—

800,000,000	tons of coal.
275,000,000	,, iron-stone

902. *The South Staffordshire coal-field* and the neighbouring district are remarkable as yielding apparently a very thick seam of coal varying from 20 to 40 feet, and locally called "the ten yard seam." This is, however, in fact composed of a number of seams (about 13) with very narrow partings, worked together, and therefore regarded as one bed. Besides the thick coal there are as many as 10 other seams known in the district. The workings are not very deep, the deepest rarely amounting to 800 feet. The quality of the coal varies, part of it being of the kind called "cannel," but the greater portion burning to a white ash. A large quantity of ironstone is found in some parts of the district, the annual make of iron being upwards of 500,000 tons. It is hardly possible to estimate the quantity of gettable coal in the South Staffordshire coal-field.

903. *The Ashby coal-field* has been estimated to contain about 1,500,000,000 tons of coals. The workings are very deep, some pits being sunk to 1200 feet. The coal-seams generally repose on fire-clay, of which a large quantity is exported.

904. *The Bristol coal-field* is much obscured, and the beds broken, so that the whole area has been described as including five chief districts. The beds are very thin, but numerous. They are also deep, so that the working is attended by great expense, most of the sink-

ings passing through overlying beds of New red sandstone, Lias, and even Oolite. A large proportion of the area is still untouched.

905. *The South Welch coal-field* is generally considered as divided into two parts—one being anthracitic and the other bituminous. The former is supposed by some writers to have been derived from the latter by exposure to heat. Without discussing this question we may state generally, that in this district the western extension of the basin is the most anthracitic, and that in addition to the two principal varieties there is a third or intermediate condition of coal now known as "steam-coal," and admirably adapted for the use of the steam-navy. This kind is extremely compact, burns without perceptible smoke, and contains so little bituminous matter as not to be at all subject to spontaneous combustion. It is found in abundance near the Port of Swansea, and is cheap. The following account of the weight of water evaporated by one pound of coal will give a practical idea of the relative value of this fuel.

Weight of Water evaporated by different kinds of Coal.

	lbs.	ozs.
Common Scotch bituminous coal	5	14
Hastings Hartley main, Newcastle	6	14½
Carr's West Hartley ditto	7	5
Middling Welch anthracite	7	15¼
Merthyr bituminous coal (S. Wales)	8	
Llangennech steam-coal ditto	8	14½
Cameron's steam-coal ditto	9	7¾
Pure Welch anthracite ditto	10	8½

The productive capacity of the South Welch coal-field is not easily ascertained, as it has been hitherto too little explored to justify any calculation as to the average thickness of workable coal. The different estimates vary from 60,000,000,000 to about 100,000,000,000 tons.

906. Almost every one of the numerous seams of coal in this district, however thin, is underlaid by a seam or bed of fire-clay containing in abundance the roots of Stigmaria (fig. 217), and many of the merely bituminous seams are characterised in the same way. The thickest seam of coal rests on about three feet of underclay, but seams not an inch thick sometimes rest upon as much as five feet of this substance, and there are also bands of it without coal. Argillaceous shale, sandy shales, and sand-rock form the associated beds, and there seems no very apparent order of succession. With these are a number of seams of iron-stone of great value producing an enormous quantity of iron; the seams are, however, generally thin, their total thickness not generally exceeding seven feet in a single shaft sinking.

907. *The coal-fields of Scotland* are estimated to equal in area those of the whole of France, and they amount to one 1-18 part of

the total area of the country and its islands. The number of detached areas is very large, and the quantity of coal worked considerable. The quality of the coal is generally dry and free-burning, not caking like the best coals from Newcastle, and inferior to the latter in the quantity of heat obtained from combustion. Most Scotch coals also yield a good deal of white ash, and they are apt to contain pyrites. Some of the richest and most valuable bands of iron-stone are obtained from the coal-measures of Scotland, chiefly from the Basin of the Clyde, and from these a vast manufacture of iron is carried on, the amount of pig-iron made last year (1849), being nearly 700,000 tons, an increase of nearly 300,000 tons on the make of 1844. The associated beds in Scotland include a very large proportion of sandstone, and a peculiar limestone bed worked at Burdie House near Edinburgh, besides a bed called the encrinite limestone. The former is a dull, earthy rock about 27 feet thick, of bluish or blackish grey colour, and often slaty texture. It contains very numerous remains of fishes, one of which (the Megalichthys) has been already described (§ 891 fig. 218), and some fossil plants, besides numerous microscopic crustaceans. The encrinite limestone worked at Gilmerton and Crichton Dean contains similar fossils with the addition of numerous encrinital fragments.

908. In Ireland there are 7 coal-districts,—1 in Leinster, 2 in Munster, 3 in Ulster, and 1 in Connaught, those north of Dublin yielding bituminous, and those south only anthracitic coal. The Leinster deposit contains 8 workable beds, and it is calculated that 120,000 tons per annum are extracted from it. The Tipperary coal-field extends about 20 miles in length by 6 in its widest part, and forms a range of hills of from 300 to 600 feet in height, the coal lying in deep troughs. The Munster field is the most extensively developed of all the Irish coal-districts, and occupies considerable portions of the counties of Clare, Limerick, Cork, and Kerry, but the coal lies in troughs as in the Tipperary district. These are all anthracitic.

909. Of the bituminous coal that of Tyrone is a small but interesting field, chiefly remarkable for the variety of rocks found in the neighbourhood. The coal-strata rest on the Dungannon limestone, and consist of the usual sandstones and shales, associated with limestone, ironstone, and fire-clay. The coal is abundant and easily obtained, 22 to 32 feet of workable coal being found within a depth or 120 fathoms.

At the northern extremity of Antrim is a small coal-field remarkable for its association with the great basaltic mass of that district, and resting immediately on mica-slate without intervening beds either of limestone or Middle or Older palæozoic rocks. At Mulvagh Bay there are 6 beds of coal, 4 bituminous and 2 anthracitic. The

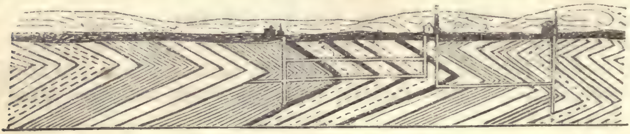
latter of these beds are fine, one immediately above and the other below a range of columnar basalt 70 feet thick which lies amongst the coal-measures.

The coal-district of Connaught is interesting as having been worked for iron-stone. Its greatest length is about 16 miles and its extreme breadth nearly as great: it occupies hills having flat summits covered with bog, presenting a straight ridge of from 1000 to 1200 feet high. The iron-stone bands are found associated with thick beds of clay-slate (shale) from 300 to 600 feet thick, and are remarkably rich. There are 3 beds of coal, the first from 1 to 3 feet thick, the second from 3 to 3½, and the last 9 inches.*

910. From the coal-measures of the British Islands we pass on now to consider the coal countries of the continent of Europe. Of these Belgium is the most important, and as the great Belgian coal-field extends also into France, we may consider these two at the same time.

There are two principal divisions of the Belgian coal-area, the one extending to the east, and known as the Liege coal-field, and the other to the west forming the Hainault division, and reaching into France at Douay. The former contains about 100,000 English acres, and the latter upwards of 220,000 acres, and in both the number of the coal-seams is exceedingly great, although many of the beds are very thin and much more disturbed and displaced than is the case with the contemporaneous English deposits. The annexed diagram (fig. 220) will give some notion both of the way in which the coal-

Fig. 220.



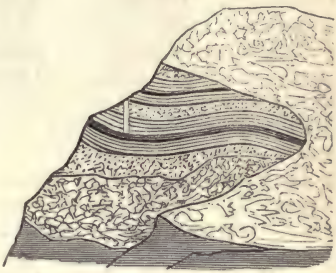
Section across a Belgian coal-field.

seams are there presented, and the apparent multiplication of them by very sharp and distinct doublings of the strata. There are said to be no less than 150 coal seams in the western division of the district. The thickness is not often great, and the position renders it necessary to adapt the methods of mining with especial reference to this. The quality of the coal is very various, including one peculiar kind, the *Flenu coal*, unlike any found in Great Britain except at Swansea. It burns rapidly with much flame and smoke, not giving out an intense heat, and having a somewhat disagreeable smell. There are nearly 50 seams of this coal in the Mons district. No iron has been found with the coal of Belgium.

* Kane on "The Industrial Resources of Ireland."

911. The most important coal-fields of France are those of the Basin of the Loire; and of these St. Etienne is the best known and largest, comprising about 50,000 acres. In this basin are eighteen beds of bituminous coal, and in the immediate neighbourhood several smaller basins containing anthracite. Other valuable localities are on the Moselle, near Saarebrück; in Alsace; several in Burgundy, much worked by very deep pits, and of considerable extent; some in Auvergne, with coal of various qualities; some in Languedoc and Provence, with good coal; others at Arveyron; others at Limosin; and some in Normandy. Besides these are many others of smaller dimensions and less extent, whose resources have not yet been developed. The total area of coal in France has not been ascertained, but is, probably, not less than 2000 square miles. The annual production is now not less than 4,000,000 tons. Most of the coal-measures of France are of the same age as the English deposits, but repose on granite or other crystalline or metamorphic rocks. The associated rocks are generally sand and shales. The coal-seams are almost all comparatively thin, and often irregular; but several ten foot seams of fair quality are found. Some remarkable cases are known in France of the enclosure of carboniferous rocks in clefts and hollows in older and crystalline rocks; but, perhaps, one of the most remarkable is that represented in the annexed diagram (fig. 221), of a coal-bed and associated sands and shales enclosed in porphyritic granite, at La Pléau (Corréze), in the province of Limosin: the coal is ten feet thick, of bituminous quality, and measures about 100 acres in extent; it is worked from a shaft.

Fig. 221.



Coal-measures in crystalline rock.

912. There are four coal-districts in Central Germany, of the Carboniferous period, besides several districts where more modern lignites occur. The principal localities for true coal are near the banks of the Rhine, in Westphalia; on the Saare, a tributary of the Moselle; in Bohemia; and in Silesia. The total annual production exceeds 2,750,000 tons. A considerable quantity of coal is also worked in Saxony. Of these various localities Silesia contains very valuable and extensive deposits of coal, which are as yet but little worked. The quality is chiefly bituminous, the beds few in number, but very thick, amounting in some cases to twenty feet. Some anthracite is found. Bohemia is even more richly provided than Silesia, the coal-measures covering a considerable area and occupying several basins.

More than forty seams of coal are worked; and several of these are from four to six feet thick.

913. The basin of the Saare, a tributary of the Moselle, near the frontier of France, affords a very important and extensive coal-field, which has been a good deal worked, and is capable of great improvement. No less than 103 beds are described, the thickness varying from eighteen inches to fifteen feet. It is estimated that at the present rate of extraction the basin contains a supply for 60,000 years. On the banks of the Ruhr, a small tributary to the Rhine, entering that river near Dusseldorf, there is another small coal-field estimated to yield annually nearly 1,000,000 tons. The whole annual supply from Prussia and the German states of the Zollverein, or Customs union, is considered to exceed 2,750,000 tons.

914. Hungary and other countries in the east of Europe, are known to contain true coal-measures of the Carboniferous period; but the resources of these districts are not at present developed. On the banks of the Donetz, in Russia, coal is worked to some extent, and is of excellent quality, but it belongs to the older part of the Carboniferous period.

915. Spain contains a large quantity of coal, both bituminous and anthracitic. The richest beds are in the Asturias, and the measures are so much broken and altered in position, as to be worked by almost vertical shafts through the beds themselves. In one spot upwards of eleven distinct seams have been worked, the thickest of which is nearly fourteen feet thick. The exact area is not known, but it has been estimated by a French engineer that about 12,000,000 of tons might be readily extracted from one property without touching the portion existing at great depths. In several parts of the province the coal is now worked, and the measures seem to resemble those of the coal-districts generally. The whole coal-area is said to be the largest inEurope, presenting upwards of 100 workable seams, varying from three to twelve feet in thickness.

916. We pass on now to the consideration of the coal-measures of the Carboniferous period, as developed in the American continents. It is only within a few years that these have been in any way known; and we are even now in ignorance of many details with regard to the greater number; but enough is ascertained to convince any unprejudiced person that the supply of mineral fuel there obtainable is amply sufficient for the requirements of the whole civilised world for thousands of years, even should the demand increase rapidly, and the consumption continue to bear reference to the multiplication of all kinds of industrial occupation. The principal source of information on this subject, and indeed generally on all subjects concerning the statistics of coal, is an admirable work, by Mr. R. C. Taylor, recently published, which we have already had

occasion to make use of in describing the principal coal-deposits of Europe.

There are in North America four principal coal-areas, compared with which the richest deposits of other countries are comparatively insignificant. These are the great central coal-fields of the Alleghanies; the coal-field of Illinois and the basin of the Ohio; that of the basin of the Missouri; and those of Nova Scotia, New Brunswick, and Cape Breton. Besides these are many smaller coal-areas which, in other countries, might well take rank as of vast national importance; and which, even in North America, will one day contribute greatly to the riches of various States. We will endeavour to give a brief outline of the main facts concerning the chief of these districts.

917. The Alleghany or Appalachian coal-field, measures 750 miles in length, with a mean breadth of eighty-five miles, and traverses eight of the principal States in the American Union. Its whole area is estimated at not less than 65,000 square miles, or upwards of 40,000,000 of acres. The area is thus distributed:—

Name of State.	Area in acres.
Alabama	2,250,000
Georgia	100,000
Tennessee..........	2,750,000
Kentucky	5,750,000
Virginia	13,500,000
Maryland	350,000
Ohio	7,500,000
Pennsylvania	9,500,000
	41,700,000

918. Making a liberal deduction for unproductive portions, denuded and eroded strata, and the parts of the seams out of reach, we may still fairly calculate that there exists in this district an area of 25,000,000 of acres of productive coal-measures. The working has already commenced in most of the States above-mentioned,

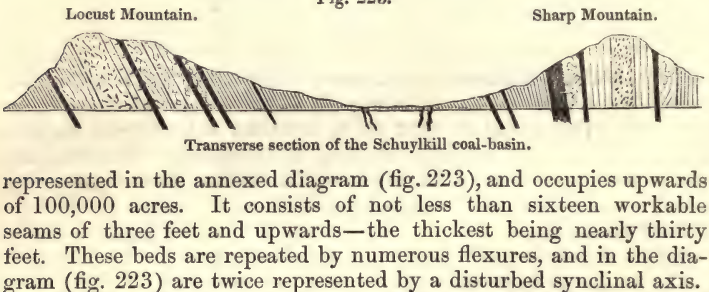
Fig. 222.

Section across the Alabama coal-fields. (Length 50 miles.)

though not generally to any very considerable extent. Thus, in Alabama, the beds alternate with the usual sandstone shales and clays, and the coal-seams worked seem to be from four to ten feet thick, and are quarried at the surface. They repose on grits, and appear on the two sides of an anticlinal, as seen in the annexed diagram (fig. 222). The coal is bituminous, and used for gas. In

Kentucky, both bituminous and cannel-coal are worked in seams about three or four feet thick, the cannel being sometimes associated with the bituminous coal as a portion of the same seam; and there are, in addition, valuable bands of iron ore. In Western Virginia there are several coal-seams, of variable thickness, one nine and a half feet, two others of five, and others three or four feet. On the whole there seems to be at least forty feet of coal distributed in thirteen seams. In the Ohio district, the whole coal-field affords on an average at least six feet of coal. The Maryland district is less extensive, but is remarkable as containing the best and most useful coal, which is worked now to some extent at Frostburg. There appears to be about thirty feet of good coal in four seams, besides many others of less importance. The quality is intermediate between bituminous and anthracitic, and it is considered well-adapted to iron making. Lastly, in Pennsylvania, there are generally from two to five workable beds, yielding, on an average, about ten feet of workable coal, and amongst them is one bed traceable for no less than 450 miles, consisting of bituminous coal, its thickness being from twelve to fourteen feet on the south-eastern border, but gradually diminishing to five or six feet. Besides the bituminous coal there are, in Pennsylvania, the largest anthracitic deposits in the States, occupying as much as 250,000 acres, and divided into three principal districts. A section of one of these—the Schuylkill—is

Fig. 223.



Transverse section of the Schuylkill coal-basin.

represented in the annexed diagram (fig. 223), and occupies upwards of 100,000 acres. It consists of not less than sixteen workable seams of three feet and upwards—the thickest being nearly thirty feet. These beds are repeated by numerous flexures, and in the diagram (fig. 223) are twice represented by a disturbed synclinal axis.

919. The Illinois coal-field in the plain of the Mississippi is only second in importance to the vast area already described. There are four principal divisions traceable, of which the first or Indiana district contains several seams of bituminous coal, distributed over an area of nearly 8,000 square miles. It is of excellent quality for many purposes; one kind burning with much light and very freely, approaching cannel-coal in some of its properties; other kinds consist of caking or splint coal. In addition to the Indiana coal-field, there appears to be as much as 48,000 square miles of coal-area in

the other divisions of the Illinois district, although these are less known and not at present much worked. 30,000 square miles are in the State of Illinois, which supplies coal of excellent quality and with great facility. The coal is generally bituminous.

920. The third great coal-area of the United States is that of the Missouri, which is little known at present although certainly of great importance. From the account given of these localities, the reader will be able to appreciate in some measure the mineral resources of the United States, and may perceive also the importance of geological knowledge in recognising the laws of position of material so valuable.

921. British America contains very large supplies of coal in the provinces of New Brunswick and Nova Scotia. The former presents three coal-fields, occupying in all no less than 5,000 square miles, but the latter is far larger and exhibits several very distinct localities where coal abounds. The New Brunswick coal-measures include not only shales and sandstones, as is usual with such deposits, but bands of lignite impregnated with vitreous copper ore and coated by green carbonate of copper. The coal is generally in thin seams lying horizontally. It is chiefly or entirely bituminous.

922. In Nova Scotia there are three coal-regions, of which the Northern presents a total thickness of no less than 14,570 feet of measures, having 76 seams whose aggregate magnitude is only 44 feet, the thickest beds being less than 4 feet. The Pictou or central district has a thickness of 7590 feet of strata, but the coal is far more abundant, one seam measuring nearly 30 feet, and part of the coal being of excellent quality and adapted for steam purposes. The southern area is of less importance. Besides the Nova Scotia coal-fields, there are three others at Cape Breton, of which one — the Sydney coal — is admirably adapted for domestic purposes. There are here 14 seams above 3 feet thick, one being 11 and one 9 feet.

923. The coal-measures of Australia and those of New Zealand are of doubtful age. Some parts of the chain of islands between the Malayan peninsula and Australia are known to contain mineral fuel, but the exact position in the geological series has not yet been made out. The same may be said of the Island of Borneo.

China appears to contain large supplies of mineral fuel, which were worked so long ago as the thirteenth century. Mr. Williams, one of the latest authorities concerning the statistics of this country, states that "several kinds, both anthracitic and bituminous, are seen in the coal-marts of the north. That which is brought to Canton is hard and leaves a large proportion of ashes after combustion. During ignition it throws off a suffocating sulphurous smoke. It is employed in the manufacture of copperas."

Much better qualities are obtained at Nankin and further northwards.

924. The following table, the analyses of English specimens chiefly selected from those by Mr. Mushet, will give an idea of the relative value of different coals :—

ANALYSES OF VARIOUS KINDS OF COAL.

Locality.	Description of Coal.	Specific Gravity.	Analyses.		
			Carbon.	Bitumen, Volatile matter, Water.	Ash.
1. Newcastle-on-Tyne ..	Bituminous	1·257	57·00	37·60	5·40
2. Lancashire	Ditto	1·260	54·90	40·48	4·62
3. Ditto	Cannel	....	56·40	41·00	2·60
4. North Wales	Bituminous	....	62·72	36·00	1·28
5. Staffordshire Potteries.	Ditto	....	62·40	34·10	3·50
6. Yorkshire	Ditto	....	67·14	30·73	2·13
7. Ditto	Ditto	....	58·38	39·51	2·00
8. Derbyshire	Ditto	1·235	52·46	45·50	2·04
9. Ditto	Cannel	1·278	48·36	47·00	4·64
10. Ditto	Cherry	....	57·00	40·00	3·00
11. Shropshire	Bituminous	....	64·10	34·77	1·13
12. South Staffordshire....	Ditto	....	54·05	42·70	3·25
13. Ditto	Ditto	....	54·17	43·33	2·50
14. Dean Forest	Ditto	....	63·72	32·03	4·25
15. South Wales	Ditto	....	60·25	33·00	6·75
16. Ditto	Ditto	....	66·02	29·15	2·83
17. Ditto	Ditto	....	70·68	25·82	3·50
18. Ditto	Anthracite	....	91·89	5·61	1·50
19. Ditto	Dry coal	....	79·50	17·50	3·00
20. Ditto	Steam coal	....	85·00	11·87	3·30
21. Clyde Valley	Bituminous	....	51·20	45·50	3·13
22. Lismahago	Cannel	....	39·43	56·57	4·00
23. Scotch coal (mean)....	Dry	....	48·81	41·85	9·34
24. Ireland, Leinster	Dry anthracitic	1·602	92·88	4·25	2·87
25. Ditto ditto	Cannel	....	79·60	12·00	8·40
26. France (mean)	Dry coal	....	79·15	7·37	13·25
27. Ditto, St. Etienne ..	Bituminous	....	65·68	27·83	6·49
28. Spain (mean)	Ditto	....	53·00	40·00	7·00
29. Belgian, Hainault	Ditto	1·276	84·67	13·23	2·10
30. Ditto, Liege......	Ditto	....	76·00	19·60	4·40
31. Ditto, ditto	Dry	1·365	81·90	9·00	9·10
32. Silesia..............	Glance	....	58·17	37·89	8·93
33. Bengal	Slaty	1·447	41·00	36·00	23·00
34. American, Ohio......	Bituminous	....	55·55	41·85	2·60
35. Ditto Alleghany ..	Dry	....	78·85	9·47	11·73
36. Ditto Nova-Scotia	Bituminous	1·321	58·80	28.20	12·95
37. Pennsylvania Ditto	Anthracite	....	92·60	2·25	2·25

No. 1, is by W. R. Johnson, mean of several. Some further details are given in § 896. No. 2, ditto, Liverpool coal. No. 3, Dunn. No. 4, Mushet, from Dee Bank, five-yard seam, compact, used for iron. No. 5, Dufrenoy and Berthier, from Apdale, nearly corresponds with Littlemine coal of Lane-end. No. 6, Mushet. Parkgate main coal, used for blast-furnace. No. 7, ditto. Worsboro' furnace-coal, mean of two. No. 8, ditto, Alfreton furnace-coal. No. 9, ditto, from Alfreton also. No. 10,

Berthier, from Butterly. No. 11, Mushet, top-coal; No. 12, ditto, ten-yard coal, Bentley estate. No. 13, ditto, Corbyn's-hall, Heathen-coal. No. 14, ditto, Coleford High-delf seam, top part. No. 15, ditto, household coal, Mynyddyslwyn. No. 16, ditto, white-ash furnace-coal, twelve-feet seam, from Risca. No. 17, ditto, Bedws ten-foot vein, south side of coal-basin. No. 18, ditto, Y stal-y-ferra works, Swansea, a six-foot seam. No. 19, ditto, Dowlais works. No. 20, ditto, also from Dowlais, a nine-ft seam. No. 21, ditto, a furnace-coal. No. 22, ditto. No. 23, W. R. Johnson. No. 24, ditto, a slightly bituminous variety from Kilkenny. No. 25, Dr. C. T. Jackson. No. 26, by Berthier, mean of 12. No. 27, M. Gruner. No. 28, ditto, mean of five. No. 29, M. Cauchy, from near Mons. No. 30, C. Davreux. No. 31, N. Delvaux, from Harion. No. 32, Richter, from Bielschowitz. No. 33, from Cherra Ponjee. No. 34, Western Virginia, Valley of the Ohio. No. 35, ditto, Percy, mean of two, from Frostburgh. No. 36, Johnson, mean of two from Pictou. No. 37, Percy, mean of 2, Mauch Chunk.

The student must not mistake the nature and use of this table. In almost every coal-district, a great difference exists in the coal taken from different seams, or different parts of the same seam. All that can be attempted by analyses of single specimens, is to give some notion of the prevailing character. Thus, the proportions of ash in various coals would be generally those quoted in the table if the ordinary condition of the coal was taken, but numerous specimens of Newcastle coal would yield much less than five per cent. of ash, and much Lancashire coal a great deal more. The percentage of volatile matter must be taken in the same way, and includes of course much carbon combined with hydrogen. Other analyses of coal will be found as follows:—§ 354, 869, 885; these are generally in greater detail.

925. The *Millstone grit* is a more or less compact gritstone or conglomerate often used in England for millstones and underlying the true coal-measures, though not unfrequently containing thin seams of mineral fuel. Thus, in Northumberland there is an area of nearly 350,000 acres of this kind, and in the West-riding of Yorkshire and Lancashire another district of 650,000 acres with thin seams, some few of which are workable, but the deposit generally contains no carbonaceous matter, except a little disseminated through the mass. Out of England the millstone grit is not generally present, and indeed the coal-measures frequently offer the only evidence of deposits of the Carboniferous period.

926. The *Carboniferous or Mountain Limestone* forms in England the true base of the upper part of the Palæozoic series, but it is by no means always present. It may be regarded as a coral reef occasionally containing bands of shelly, encrinital or other remains, and numerous fragments of fishes. Sometimes, also, bands of impure coal occur, which in other countries are of greater value and extent than with us. In the South-western extremity of England, imperfect coal-measures, called *culm*, replace the carboniferous limestone, and this is the case also in Russia and perhaps elsewhere. In Ireland a peculiar sandy deposit terminates the series. Some of the common fossils of this period have been already figured (see figs. 143, 156), and others are represented in the annexed diagrams (figs. 224, 225, 226). Besides these, however, there are many others found, some of which are regarded as characteristic.

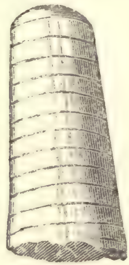
927. The following is the arrangement of the Carboniferous fauna in England. Almost all the species belong to the lower part of the series:—

Amorphozoa	1
Zoophytes	73
Encrinites	73
Annelids	13
Insects	2
Crustaceans	52
Brachiopoda	184
Conchifera dimyaria	164
——— monomyaria	138
Gasteropoda	162
Pteropoda	1
Heteropoda	23
Cephalopoda	134
Fishes	130
Total species	1,150

Fig. 224.

Fig. 225.

Fig. 226.



Group of Carboniferous fossils.
Fig. 224. Cyathocrinites planus.
,, 225. Euomphalus pentangulatus.
,, 226. Orthoceras lateralis.

928. *The culmiferous series* of Devonshire occupies a great trough, the axis of which ranges east and west and extends for about fifty miles, with a breadth of between thirty and forty miles. Crossing the edge of this trough, we find a black limestone, overlaid by siliceous flagstones; and these are followed by sandstones and carbonaceous and calcareous shales, which gradually become harder, and pass into siliceous bands of a dark colour, with earthy carbonaceous partings, surmounted by a regular thick-bedded sandstone, resembling the gritstones of the coal-measures.

929. The beds, the order of whose superposition has been just mentioned, form, with a black carbonaceous shale and a black limestone, the lower subdivision of the whole Carboniferous system, as developed in the south-west of England. The order is somewat different, however, towards Dartmoor, for there an irruption of granite

has taken place since the deposition of the strata, and the vicinity of the crystalline rock has produced confusion and violent distortion. Notwithstanding this, and the frequent repetition of these beds by faults and disturbances, they are satisfactorily proved to be of great thickness; but they contain few fossils, and differ in lithological character from the rocks, probably of the same age, in the middle and north of England.

930. The upper culm-measures of Devonshire are the newest beds of the district, and occupy nine-tenths of the whole surface of the carboniferous deposit. This group is composed of sandstones and indurated shales (the latter containing the *culm*), and is of great, but unascertained thickness, being perpetually interrupted, coiled upon itself, and repeated over again, forming an incredible number of anticlinal and synclinal lines, all of them ranging east and west, parallel to the strike of the beds.

There is, however, no difficulty with regard to the general order of superposition, or the extent and real thickness of this part of the deposit, for both on the northern and southern outskirts of the formation a great ascending series is seen, throughout the whole of which the dip is tolerably regular.

931. The sandstones of this group are generally close grained, and of a grey or greenish grey colour, passing occasionally into flagstone and laminated arenaceous shale, with fine ripple marks at the partings. The shales vary in appearance from sandy beds to soft slaty clays, not to be distinguished from the common coal shales; and amongst these latter are occasionally found dark carbonaceous bands, containing obscure vegetable markings, discoloured by pyrites.

932. Such are the prevailing characters of the beds which form the culmiferous series of Devonshire: these beds being the true representatives of the Carboniferous system. Notwithstanding the general paucity of fossils, one or two species of shells are not to be distinguished from species well known in the mountain limestone; and the result of a comparison of the remains of plants from the culm, with those commonly met with in rocks of the Carboniferous period, tends yet more strongly to establish the contemporaneity of the two deposits. Considering the thickness of these culm-measures in Devonshire, they might represent the whole mass of the mountain limestone; and the different mineral character of the rocks, dependent on the circumstances under which they were respectively formed, might account for considerable alterations in the fossils, and must have had great influence in modifying the forms of animal life.

933. The Carboniferous system, as exhibited in Yorkshire and Derbyshire, consists of a magnificent development of mountain limestone, to whose presence the picturesque scenery of those counties is due, the limestone being partly overlaid on the east, west, and north,

by the millstone grit. The lower part of the millstone grit, however, is sometimes represented by a series of laminated and often bituminous shales, which rest immediately on the limestone and contain some bands of iron-stone, and a few thin black limestones; while the upper part consists of several hundred feet of pebbly grits and other sandstones alternating with thin bad coal.

934. Further north, and in the north-western part of Yorkshire, the mountain limestone becomes a still more important and prominent member of the Carboniferous series, and is capable of local subdivisions. It is here subdivided into two groups, whose total thickness is about 1800 feet. Of these two the lower, the *Scar limestone,* forms bold bluff precipices, and is pierced in many places by large natural caverns; and both here and in the upper strata (the Yoredale rocks), the limestone is remarkably different from the contemporaneous beds in the south, containing thin seams of coal, sometimes worked, and divided into several beds by partitions of grit and shale. The Yoredale rocks thus contain at least five distinct beds of limestone, alternating with freestones, flagstones, &c., and attaining a thickness of as much as a thousand feet. In the north-west of England, where the mountain limestone is developed in the same manner, the upper beds of the series, the millstone grit, and the true coal-measures, are scantily exhibited; but in the north-east, as in Northumberland, the Scar limestone is much broken by the interposition of pebbly grits, shales, and coal-seams, which entirely change the character of the formation.

935. In Ireland the mountain limestone occupies an important place, and consists of two great bands of limestone, with a considerable thickness of shale and argillaceous limestone and sandstone interposed, which are known by the name of *calp* or calp slate. It is chiefly, however, in the northern and middle districts that the calp is found, and it gradually thins out towards the south. Beneath the lower limestone another series of schistose beds (the *carboniferous slate*) occurs, and this rests on sandstone beds, often alternating with shale, and occasionally with limestone. The "carboniferous slate" of the south of Ireland differs in lithological character from that of the middle and northern regions, but, from the evidence of fossils, the two must be looked on as contemporaneous.

936. On the continent the Carboniferous beds are similarly developed; the lower beds in Westphalia passing into calcareous shales, containing fossil remains of the carboniferous type. These, therefore, are assumed as the base of the Carboniferous system. They are immediately succeeded by a group of black imperfect limestones and siliceous schists (*Kiesel-schiefer* of the Germans), considerably expanded and traceable for some distance, and looked upon as the equivalents of the English mountain limestone, the underlying beds

representing the shales occasionally met with in England when the sequence to the older rocks is complete.

937. The black limestone is extremely carbonaceous, argillaceous, and fetid, and it corresponds so entirely in mineral character with the culm limestone of Devonshire, that the description of the one rock might almost serve for the other, not merely as regards its general appearance and lithological character, but also because the organic remains,—the Goniatites and Posidoniæ,—with which the rocks in Devonshire are loaded, are in Westphalia also by far the most abundant fossils of the deposit. On the continent, however, the culm limestone passes upwards into another limestone of a lighter colour, and this bed contains all the most characteristic fossils of the true English mountain limestone.

938. Advancing still further eastwards we find in Russia that the lower carboniferous beds consist of incoherent sandstone, alternating with a bituminous shale, which sometimes contains thin bands of impure coal and impressions of plants ; the whole being surmounted by various beds of limestone, which form the central group of the Carboniferous system. Of these beds, the lowest is usually of a dark colour, as in other parts of Europe ; but the middle, and most extensive, differs entirely from any contemporaneous rock, being of a milk-white colour resembling chalk, and loaded with flints. It is also of considerable thickness, and extremely fossiliferous, and alternates with beds of compact yellow magnesian limestone, and bands of red or greenish shale or marl, while associated with it there are splendid masses of white gypsum and thin bands of limestone interstratified. The third, or upper division of the series, is scarcely less remarkable than the central, being almost entirely made up of myriads of fossil bodies (called *Fusulina*), resembling grains of wheat, and forming a limestone which is of considerable thickness, and appears in the lofty cliffs which occupy the banks of the Volga, and also in the coal region between the rivers Dnieper and Don.

939. In Northern Russia, and in the upper beds of the Volga, the central limestone of the Carboniferous system is totally devoid of coal, which is found in shales and sandstones, interstratified with thin courses of limestone in the lower part of the series, and in this respect exhibits a resemblance to the lower beds of the mountain limestone in Yorkshire. In the south of Russia, on the other hand, the central beds of the Carboniferous system are occasionally productive of good bituminous as well as anthracitic coal, offering, in some points, very striking analogies in mineral condition to the great South Welsh basin. The northern beds are nearly horizontal, but the coal-field in the south appears to have been disturbed, and to have been broken up by faults.

940. North America presents some interesting points with respect to the rocks now under consideration. The Carboniferous series of Pennsylvania is based upon massive sandstones, conglomerates, and shales, overlying a bed of fossiliferous limestone. Resting upon this group, which is of great and uniform thickness, there is a deposit of red shale, which varies in thickness from 3000 to less than 100 feet, and is supposed to thin out and disappear to the south-west; and this is partly overlaid and partly replaced by a hard coarse conglomerate, very thin towards the north-west, but rapidly swelling out, and becoming from 800 to 1200 feet thick towards the south-east. None of these formations contain profitable coal, although the remains of plants are found in them, and a few seams about a foot thick occur in the red shales. The coal-measures themselves form the uppermost part of the series, and consist of micaceous sandstones, arenaceous, argillaceous, and carbonaceous shales, and valuable beds of limestone.

941. In other parts of the same wide area the Carboniferous series manifests similar peculiarities of structure. Thus, in Nova Scotia, and elsewhere in Canada, the lower beds consist of carboniferous limestone; but at Cape Breton the millstone grit appears to terminate the sequence. Newfoundland, also, which presents not less than 5000 square miles of country, occupied by contemporaneous beds, has hitherto afforded no coal.

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942. The coal-fields near Calcutta, those of New South Wales, and those of Van Diemen's Land, have been sometimes regarded as of newer and sometimes of older date than the period we are now considering. Perhaps they may, with some probability, be referred to the base of the true carboniferous rocks.

The two latter (Australian) districts present several seams of coal in horizontal beds, alternating with slaty clay, sandstone, and shale, together with a rock resembling millstone grit, and a hard cherty rock. Seams of iron ore accompany the coal. The coal is of tolerable quality, and is being worked. Near Lake Macquarie there are five beds described, having a total thickness of nineteen feet in 204 feet of strata; the two principal seams being five feet, and the others three feet thick respectively. The one at present worked is not more than twenty fathoms below the surface, and not more than twenty yards from the water.

943. Near Burdwan about 130 miles north-west of Calcutta, a small coal-area exists, and has been long worked for an indifferent coal. The beds are eight in number, the largest being four feet and the others much smaller, giving a total thickness of twenty-four feet of coal. This coal burns with much flame, but does not cake, and is accompanied by iron ore. There are many other coal-areas of the

same geological age in the vicinity, some of which have been partly described. Amongst these is one to the North-east where the coal is of superior quality; but local circumstances have interfered with the working. Several other small Palæozoic coal-fields are described in various parts of the East.

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944. The Carboniferous series is not only remarkable for its coal, it contains also large and very important supplies of metalliferous ores, chiefly of iron, lead, and zinc. The latter are contained generally in dykes or veins, expanding against particular bands of carboniferous limestone, and often influenced by the presence of crystalline rocks. The lead mines of Derbyshire, Alstonmoor, and other parts of Northumberland and Durham, exist under circumstances of this kind, and are often found with veinstone of fluor spar, barytes and calc spar.

945. The condition of the iron ore in the coal-measures of England, Belgium, France, and America, is well-known to be that of carbonate and oxide mixed with a large percentage of clayey impurities. The concretionary structure generally prevails, and the bands consist of nodules, sometimes laminated, and sometimes concentric, but usually of flattened spheroidal shape. They often enclose leaves and other organic remains. The following accounts of the statistics of the iron trade will afford the best information as to the extent to which the iron-stone of the British islands is an important mineral. The details of the iron mines of England will be found in the next chapter.

Production of iron in 1845.*

	Tons.		Tons.
		Brought up	3,850,000
Great Britain	2,200,000	Austria	190,000
United States	502,000	Belgium	150,000
France	448,000	Sweden	145,000
Russia	400,000	Spain (1841)	26,000
Zollverein	300,000	Rest of Europe	50,000
	3,850,000		4,411,000

Production of iron in Great Britain.†

	1830.	1840.	1843.
South Wales	277,643	505,000	457,355
South Staffordshire	212,604	407,150	300,250
Scotland	37,500	241,000	238,550
Shropshire	73,418	82,750	76,200
Yorkshire	28,926	56,000	42,000
Derbyshire	18,000	31,000	25,750
Northumberland	5,327	11,000	25,750
North Staffordshire	....	20,500	21,750
North Wales	25,000	26,500	19,750
Forest of Dean	....	15,500	8,000

* Taylor's "Statistics of Coal," Introduction, p. xxix.
† Report of Brit. Assoc. for 1846, p. 118.

CHAPTER XVII.

ON THE ROCKS AND FOSSILS OF THE OLDER PART OF THE PALÆOZOIC EPOCH.

3. *The Devonian, or Old red sandstone system.*

946. The various rocks called by English geologists Devonian or Old red sandstone, according to the different circumstances under which they appear, are recognised under nearly the same name in France and Germany, and include also many of the so-called greywacke schists of the latter country.

The following are the principal subdivisions of the group.

OLD RED SANDSTONE SERIES.

HEREFORDSHIRE.	SCOTLAND.
Old red conglomerate	Quartzose yellow sandstone. Impure limestone. Gritty red sandstone.
Cornstone	Grey fissile sandstone.
Cornstones and marl	Red and variegated sandstones. Bituminous schists. Coarse gritty sandstone. Great conglomerate.

DEVONIAN SERIES.

DEVONSHIRE.	BELGIUM.
Calcareous grits and impure limestones	Indurated shale and psammite. Calcareous shales.
Red flagstones	Lower limestone of Belgium.
Calcareous slates and Plymouth limestones	Hard siliceous beds and conglomerates.

The fossils of this period include many species of corals, encrinites, and shells; of the latter of which a few characteristic species are figured in the annexed cut (figs. 227—230). Others are represented in figs. 138, 151, 160. There are also a number of remains of fishes, some of very great interest from the remarkable peculiarities of form and structure which they present. Many of these are small, but others of gigantic proportions.

947. The Old red sandstone of England and Wales consists of various strata of limestone, marl, and sandstone, alternating with great thicknesses of conglomerate, which often pass upwards into overlying sandstones, and the series is expanded over a considerable portion of our island, rising into lofty mountains, occupying extensive plains, and developed to an enormous thickness.

948. In North Wales, although the Old red sandstone retains its general character, we find it inferior in thickness and importance to its development in Herefordshire and South Wales. It again

increases, however, as we advance still further northwards into Westmoreland and Cumberland, where it appears as an irregular conglomerate. In this part of England its largest development is near the foot of Ullswater, and it rises into a succession of round topped hills several hundred feet high, the beds being of great thickness. No true passage is there discernible into the overlying limestones.

Fig. 230.

Fig. 227.

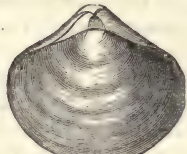
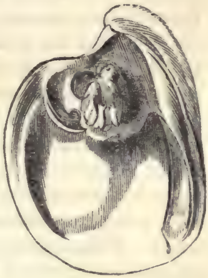


Fig. 228.

Fig. 229.



Group of Devonian fossils.
Fig. 227. } Terebratula porrecta.
,, 228. }
,, 229. Magalodon cucullatus.
,, 230. Clymenia linearis.

949. The loftiest points occupied by this deposit are the Vans of Caermarthen and Brecon, the former 2590, and the latter 2500 feet above the level of the sea. These hills are made up of a conglomerate, composed of white quartz pebbles embedded in a red matrix; and it is this *quartzose conglomerate* which gives its name to the uppermost group of the formation.

The highest beds of the series do not, however, always consist of conglomerates, but are more frequently composed of beds of sandstone, hard and finely grained, and alternating with a few imperfectly exhibited mottled marls. The lower portion capping the escarpment of the cornstone in Herefordshire, furnishes thick beds of valuable building material, and is occasionally quarried for tiles. The upper beds are, for the most part, less compact, and commencing as a fine conglomerate they afterwards become coarser, and alternate with bands of red and green argillaceous marl. Fine examples of the conglomerate beds (attaining near Abergavenny a thickness of 200 feet) may be seen on the banks of the Wye, between Ross and Monmouth, and again on the right bank of that beautiful river, to the north of Tintern Abbey.

950. The *cornstone* consists of a number of argillaceous marly beds, sometimes alternating with sandstone and sometimes with impure limestone, affording, by decomposition, the soil of the richest tracts of Herefordshire and Monmouthshire. The lower part of this rock very often contains flaggy beds, some of which are extensively quarried near Downton Hall, the stone being of a greenish colour, and highly micaceous, and usually more or less intermixed with party-coloured marls, or soft argillaceous sandstones, not so compact as the rock which encloses them. The surface of the sandstone is frequently worn into irregular holes and patches.

951. But the subdivisions of the sandstones are too entirely local to allow of any lithological character being given, which can apply to more than a very limited district. Generally speaking, the impure concretionary limestone, which is more especially denominated cornstone, appears at intervals in irregular lenticular masses throughout the district, contracting and expanding in the most capricious manner ; sometimes replaced by finer and more crystalline limestone, and sometimes alternating with hard flaggy sandstones. Nearly the whole of the central and northern parts of Herefordshire, and the contiguous parts of Shropshire and Worcestershire, are occupied by this formation ; and its vast thickness is well displayed in the hills crossed by the new road from Leominster to Hereford. In the northern portion of the range, and near the mouth of the Towey, in Caermarthenshire, the limestones are most fully developed, becoming much thicker, and also more crystalline, than in other parts.

952. In Scotland the uppermost beds are highly arenaceous, and often consist of sandstone conglomerates. The intermediate calcareous band is barren of fossils, and is of somewhat singular composition, yielding unequally to the weather, and exhibiting a brecciated aspect. It contains masses of chert exceedingly hard, and these, from the manner in which they are incorporated with the rock, appear to have been of contemporaneous origin. The bed is several yards in thickness, and is very persistent, being found both in Moray and in Fife, localities 120 miles apart.

953. The middle group of the Old red sandstone of Scotland, corresponding to the cornstone of England, is developed in Forfarshire, in Morayshire, and in the grey sandstone of Balruddery, where the lower beds are absent. It is represented as consisting, for the most part, of rocks of a bluish grey colour, sometimes, as at Balruddery, resembling the Silurian mudstones, at others forming a hard fissile flagstone exported as a paving stone, and occasionally appearing in beds of friable stratified clay, easily washed away by the sea. The colour, however, throughout is grey, and in this respect differs essentially from the English contemporaneous beds, which are chiefly red and green marls.

954. The base of the whole system is represented by Mr. Miller as consisting of an extensive and thick conglomerate rising into a lofty mountain-chain in the county of Caithness, and attaining an elevation of 3500 feet in the hill called Morrheim, but a great thickness of arenaceous strata, containing conglomerates of various magnitude, intervenes between these and the middle beds.

955. The Devonian beds present a series so distinct that no relations of mineral or mechanical condition can be traced between them and the Old red sandstones. The upper beds on which the culms of Devonshire repose consist of coarse red flags and slates, sometimes alternating with or overlaid by other slates and limestones, while the lower beds are to be sought for among the calcareous slates of Cornwall and South Devon. These calcareous slates are occasionally fossiliferous, and are based upon an impure limestone. The Plymouth limestone in the south, and a group of coarse arenaceous beds in the north of Devon, together with the general series of Cornish rocks, are all included among these calcareous slates. Throughout the whole series fossils occur, but they are very unequally distributed, being locally abundant, although, owing to the metamorphic character of many of the beds they are sometimes much altered, and frequently obliterated.

956. The development of the Old red sandstone and the contemporaneous beds in Ireland is peculiarly interesting, as completing within the circuit of our own islands the whole of the chain of evidence necessary to establish the true place of the Devonian greywacke. In the south of Ireland, as in the south of Scotland, the sequence is perfect from the upper beds of the Silurian system into the lower beds of an extensive series of coarse conglomerates, which there represent the Old red sandstone, and these pass upwards through the numerous gradations of the same formation in Herefordshire, until they are at length replaced by roofing slates, resembling those at the base of the culm-measures of Devonshire, and are finally succeeded by similar strata,—the coal-fields of the south of Ireland assuming the exact character of the Devonian culm. It is clear that the formations in Devonshire, containing fossils which are intermediate in character between the Carboniferous and Silurian systems, must themselves occupy an intermediate position, and must therefore be on the parallel of some part of the Old red sandstone, which is thus shown to fill up the whole intervening space.

957. In Belgium and Westphalia the beds of the middle part of the Palæozoic period commence with a series of 1500 feet of strata, chiefly composed of coarse, yellowish sandstone, sometimes changing to grey micaceous flagstone, and alternating with shales and calcareous beds ; indicating clearly that this and the overlying deposit of mountain limestone were absolutely continuous and linked together

by a gradual passage. Below this occurs a series of alternating beds of an open-grained, yellowish sandstone (*psammite*) and of indurated shale or earthy schist; its total thickness is very great, and in both the lower and upper parts there occur limestone-bands, and bands of calcareous shale, extremely fossiliferous, and indicating an approach to the Carboniferous system.

Without any break of continuity, or any appearance of interrupted sequence, these beds pass into a mudstone, a rock whose mineral characters resemble, in many respects, those which mark some Silurian beds of England.

958. The lower limestone of Belgium, underlying this series, is well defined and of great thickness. Both by the evidence of sections and by fossils, it has been ascertained to be contemporaneous with the true Devonian limestone, and it appears identical with that of South Devon, and with the corresponding beds in Westphalia.

The whole group is of great thickness and is fossiliferous; but the line of separation by means of fossils has not been clearly made out, the upper part of the mass being unquestionably Devonian, while the lower beds seem to pass into Silurian strata, and contain fossils common to both formations.

Other beds of the same age have been found in various places in Westphalia and on the banks of the Rhine; and they are frequently greatly disturbed and contorted, presenting numerous examples of irruptions of melted rock of much newer date than that of the deposits.

959. The Devonian, or Old red sandstone formations of Russia, occupy a tract nearly as large as the whole of the British Islands, and they rest conformably upon low plateaux of Silurian rocks, attaining heights of from 500 to 900 feet above the sea level.

In different parts of the large tract of land occupied by formations of this geological period, there occur varieties of mineral composition and lithological character quite as great as those already described in speaking of the contemporaneous rocks in our own country and Germany; and the fossils consist of nearly all those which are most characteristic of the different beds in each, together with a few species not met with in Western Europe.

960. On the flanks of the Ural chain the Devonian rocks, overlying Pentamerus limestones, appear in the form of limestones and schistose beds with grits, the limestones resembling, in their dark colour and sub-crystalline aspect, those of South Devon, and the whole group quite as dissimilar from that occurring in the flat regions of Russia, as are the rocks of the same age in the south-west of England from the conglomerates and tilestones of the Old red sandstone.

961. In the heart of Russia, again, there exists a great dome-like

elevation, which rises to the height of about 800 feet above the level of the sea, and is composed of strata loaded with fossils characteristic of the Devonian system. But these strata are very unlike any other known Devonian beds in their lithological character, being composed of yellow and white marlstones and limestones, the latter often magnesian, and so accurately resembling the *Zechstein* of Germany (quite the top of the Palæozoic system),—that, were it not for the evidence derived from fossils, they would inevitably be referred to the same period as this latter bed.

962. It is interesting to find that the Devonian system, which occupies so important a place in European Geology, is repeated on the continent of America, with nearly the same lithological characters, and the same species of organic remains. In the Western States of North America, towards the Alleghanies, a group of about 150 feet of strata has been described, strikingly resembling the lower part of the Old red sandstone of Scotland, and containing similar species of fossil fish. These rocks thicken out towards the east, preserving their lithological peculiarities, and attaining a thickness of 1000 or 1500 feet in the neighbourhood of New York, where they pass insensibly into the carboniferous strata. In other parts of North America, as, for instance, in Canada, it seems almost certain that contemporaneous beds exist.

Devonian beds occur also in South America, in the Bolivian Andes, and in the Falkland Islands, while other portions have been detected in Australia, and probably occupy a part of several of the islands of the Southern hemisphere.

963. The slates and schists of the Devonian period in Devonshire and Cornwall are not unfrequently traversed by systems of veins containing metalliferous ores of various kinds. Dykes of crystalline rock also are met with, proving that many important disturbances connected with the protrusion of crystalline rock must be regarded as more modern than the period of the accumulation of these strata. The metals most abundant in Devonian rocks in the British Islands are copper and tin in the east and west veins, and lead, zinc, and silver in those transverse to this principal direction.

4. *The Upper Silurian series.*

964. The Upper Silurian rocks of England are chiefly developed in the counties of Shropshire, Radnorshire, and Herefordshire, and the whole group may be conveniently divided into three parts, according to the following Table :

1. Tilestone.	
2. Ludlow Formation	Upper Ludlow shale. Aymestry limestone. Lower Ludlow shale.
3. Wenlock Formation....	Wenlock limestone. Wenlock shale.

The Silurian rocks are so named from the districts in which their main divisions and best developed series were first discovered and described. The district in question—a portion of South-Wales and the adjoining counties of England—was formerly inhabited by the *Siluri*, a tribe of ancient Britons, and was investigated geologically by Sir Roderick Murchison, with a view to the determination of a well-marked series of rocks more ancient than those of the Carboniferous system.

965. The *Tilestone* has usually been described as the lowest member of the Old red sandstone series, but is now regarded as Silurian, and possesses very marked characters both in structure and fossil contents. It is clearly defined, occupying the loftiest parts of the escarpments of a wild mountain range, attaining an elevation of 1500 to 1600 feet, and running from Llangadock, in Caermarthenshire, in a north-easterly direction through Brecknockshire, to Builth on the borders of Radnorshire.

Throughout this extensive range of highly inclined beds tilestones are extensively quarried, and consist of hard finely-laminated micaceous and quartzose sandstones of a greenish colour, usually associated with reddish-coloured shales, which decompose into a red soil, therein generally distinguished from the Upper Silurian rocks, which decompose into a grey soil. In this part of the system organic remains are abundant in particular localities, and often indicate the lines of deposit, when transverse cleavage and the faces of joints would otherwise render the bedding difficult to be distinguished.

966. The upper beds of the Upper Ludlow rock—those, therefore, which form the next in order of the beds of the Silurian system—consist chiefly of yellowish sandstones of very fine grain, and slightly micaceous, which succeed the calcareous strata just described, with the intervention of a greyish coloured stone. Near Downton Castle there is a bed of greenish-grey argillaceous sandstone, resting on these sandy and flaggy beds, and almost made up of the remains of fucoids and the columns of some soft zoophyte, which is overlaid by another fossiliferous bed, seldom exceeding a few inches in thickness, and occasionally dwindling to a quarter of an inch. This singular stratum is a matted mass of the scales, defensive fins, jaws, teeth, and coprolites of fishes, united together, with a few small shells, by a cement in which variable proportions of carbonate of lime, iron, phosphate of lime, and bitumen are disseminated. Above this, again, a succession of micaceous sandstones passes insensibly into the lower beds of the Old red sandstone.

967. The central mass of the Upper Ludlow formation is made up of strata, containing more calcareous matter than the lower shales; and this imperfect limestone, being mixed with an argillaceous paste, forms a tolerably durable building stone. The best stone quarried for such purpose occurs in beds not exceeding eight inches in thickness; and its surface is frequently marked by undulating ridges and furrows, supposed to be due to the rippling action of the waves, when

the bed formed the surface-bottom of the sea, and the sediment was still soft. Markings, resembling those which would be made by the passage of the smaller marine animals over sand and mud, are also common on these furrowed surfaces.

968. The *Aymestry* or *Ludlow limestone* differs considerably from the Wenlock limestone, both in its general appearance, and in its having a less concretionary structure. It is sub-crystalline and highly fossiliferous, and is fully developed near the village of Aymestry, in beds from one to five feet thick, which are of an indigo or bluish-grey colour, mottled with white, and contain numerous layers of shells and corals. Near the village of Downton-on-the-rock, this limestone is well seen in a vertical cliff, the beds dipping at an angle of about 25° N., and being not less than fifty feet in thickness.

This intermediate calcareous band is frequently absent in localities where the other portions of the Ludlow formation appear; but, when present, it may usually be identified as well by its lithological peculiarities as by a remarkable fossil (*Pentamerus Knightii*), (fig. 231, 232), characteristic of it.

Fig. 231.

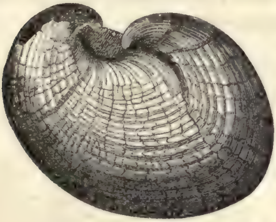


Fig. 232.

Pentamerus Knightii.

The lower beds of the Upper Ludlow formation sometimes pass by a series of gradual changes scarcely perceptible into the Aymestry limestone, and may even be grouped with it when the former happen to be concretionary and calcareous. These lower beds are, however, much more frequently argillaceous, and well entitled to the name of *mudstone*, which is often applied to them, as well as to the Lower Ludlow shales. It is usually only the transition beds from the underlying limestone, that are at all calcareous; and these are also remarkable for being absolutely loaded with the shells of a species of Brachiopoda, (*Terebratula navicula*), which is exceedingly common wherever this rock makes its appearance.

969. The next rock in order of date—*the Ludlow shale*—resembles, in colour, appearance, and want of cohesion, the middle shales of the Wenlock group, and occurs in valleys, between the Wenlock and Aymestry limestone. The steep escarpments of several hills west

of Ludlow expose the outcrop of the strata; and their junction with the underlying Wenlock limestone is marked by a series of friable stone-bands, containing corals and spheroidal concretions of clayey limestone, alternating with beds of clay. The concretionary character of the lower part of the series is very remarkable; and the concretions are almost invariably formed upon some organic body as a centre.

The main portion of the Lower Ludlow formation is composed of dirty shales, locally called *mudstones;* but these shales change towards the upper part, and become slightly calcareous. They are then succeeded by sandy flag-stones, also containing calcareous matter, and are separated by courses of soapy clay (sometimes used as fuller's earth), from the overlying beds of limestone.

970. The *Wenlock* or *Dudley limestone* forms, in some tracts, the most prominent feature in the geology of this lower division of the Upper Silurian strata, and is admirably exhibited in the rock on which Dudley Castle is so picturesquely placed, and also in the beautiful escarpment of Wenlock edge. The remarkable physical features of this bed of limestone, and the singular abundance of fossils, of which the annexed diagram (figs. 233, 234) represents two common forms, are well known and highly characteristic.

Fig. 233.

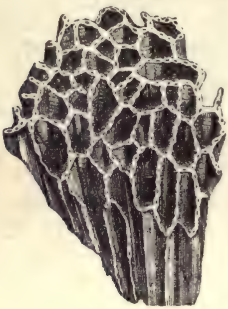
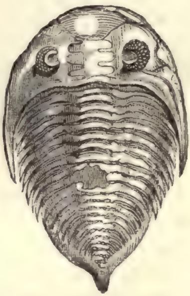


Fig. 234.



Silurian fossils.
Fig. 233. Catenipora escharoïdes.
„ 234. Asaphus caudatus.

The Wenlock limestone formation rests conformably on the Wenlock shale, and is made up chiefly of concretions of argillaceous limestone, extremely fossiliferous, separated from one another by beds of shale. The concretions are massive, and valuable for lime-burning, the best of them being quarried to a considerable extent. They are of irregular thickness and magnitude, and are surrounded and enclosed by beds of impure clay and shale; the clay entering into the

innumerable interstices and crevices of the limestone, and giving it a singular mottled appearance.

971. Occasionally, however, beds of argillaceous limestone alternate with shale; and at Wenlock Edge, and elsewhere, the whole series is both overlaid and underlaid by a number of small concretionary nodules of grey limestone, running in layers, and held together by shale, with which the nodules sometimes unite, and form irregular and thin beds of lenticular limestone.

The nodules, so common in the Wenlock limestone, are found also in other parts of the formation, and are usually crystalline, and full of corals and encrinites; the whole group of the Wenlock series, indeed, may be said to consist of numerous concretionary masses, separated from each other by a vast predominance of argillaceous matter.

972. The *Wenlock shale*, sometimes called the Dudley shale, consists of a great development of dirty-looking argillaceous beds, rarely micaceous, and containing, here and there, a few lumps of impure argillaceous limestone. The colour of these beds varies from a pale grey to dark grey or black; and, according to Sir R. Murchison, the line of separation between the Upper and Lower Silurian beds is best drawn where the hard sandy, and sometimes calcareous strata, at the top of the Caradoc sandstone, are succeeded by these softer shales. Calcareous concretions are met with occasionally, both in the lower and upper portions, and the laminæ of deposit are not unfrequently indicated by large spheroidal lumps; but the central beds are soft, incoherent, and easily washed away, an instance of which is seen along the escarpment of Wenlock Edge, where the deep valleys, between that ridge and the Caradoc hills, indicate the extent of denudation that has taken place in this part of the series.

973. In the north of England, the upper part of the Silurian system is exhibited in a series of sandy flagstones, with imperfect slaty bands, based on calcareous slates and the limestone of Coniston Water-Head. The slaty bands are sometimes calcareous, but do not contain limestone fit for use; and the series terminates with red fossiliferous strata, the fossils occurring in concretions of limestone, and the whole being overlaid by the marls of the Old red sandstone. The Silurian group, in this district, although repeated by several undulations, is still of great thickness, and contains several fossils peculiar to it but the greatest portion are of known Upper Silurian types.

On the whole it appears, that certain common lithological characters pervade most of the strata of the Upper Silurian formations in England; but that, while the subdivisions established by Sir R. Murchison are persistent throughout a large tract of Shropshire, Radnorshire, and Herefordshire, their lithological details as

might indeed have been anticipated, do not apply to other and distant parts of the country. In the Silurian district the total thickness of the two formations (the Wenlock and Ludlow) is very considerable, and it is probably much greater in some parts of North Wales; while the beds throughout exhibit every appearance of slow deposition in the finely laminated shales and micaceous fossiliferous sandstones which abound in them.

974. The Silurian rocks, though very distinctly divided into an upper and a lower series in the British Islands, or at least in some parts of them, are by no means so completely distinguished in other parts of the world. Still, the upper division has been well traced in various parts of Scandinavia, Russia, and North America, having closely allied species of fossils, both of shells and other bodies, and there can be little doubt of real contemporaneity.

5. *The Lower Silurian series.*

975. Under this name we include all those fossiliferous beds hitherto described which underlie the Wenlock shale. In the typical Silurian district these are the Caradoc sandstone and the Llandeilo flags of geologists, but in North Wales the Lower Cambrian, and in Cumberland the Lower Cumbrian systems of Professor Sedgwick must be considered as representatives. The very great extent and thickness of the beds of this earliest period, the metamorphism of many of the rocks, and the wide range of a few similar or identical fossils, all combine to give considerable interest to the group of Lower Silurian rocks.

976. *Caradoc sandstone* is the name given to a range of fossiliferous sandstones, with calcareous bands, whose mineral structure and lithological character are variable, the uppermost beds being micaceous and thinly laminated, containing bands of impure sandy limestone and thin courses of sandstone, full of shells and fragments of shells. Calcareous bands, exceedingly fossiliferous and sometimes burnt for lime, succeed to these, and alternate with sandy and pebbly gritstones; the upper grits being of a reddish brown or yellow colour, and overlaid by thick-bedded, finely-grained, siliceous sandstones, much quarried for flags and building stone. Irregular patches and occasional courses of limestone are distributed through this rock, and 300 or 400 feet of flaggy beds succeed, composed of fine grained sandstone of a green colour, and slightly micaceous. These latter beds are fossiliferous and finely laminated; but they are almost entirely devoid of argillaceous matter. Where the sections are best exhibited, there occurs in the lower part of the group a deep reddish purple sandstone, mixed with clay, and marked with greenish streaks.

977. The base of the system, as recognised by Sir R. Murchison in the Silurian region, consists of a series of hard, dark-coloured, sandy,

or gritty beds, readily splitting into flagstones; which are largely developed near the town of Llandeilo in Caermarthenshire, and are thence called *Llandeilo flags.* These beds are slightly micaceous, and frequently so calcareous as to contain true limestones. The Plynlimmon and Bala rocks of North Wales belong to this part of the series.

978. The various beds of the Lower Silurian series are repeated by a large number of folds throughout North Wales, presenting a number of remarkable structural peculiarities in that country, where the extreme complexity of the phenomena long rendered it almost impossible to arrive at any satisfactory conclusion. Now, however, that the whole district has been carefully surveyed and mapped, there seems little doubt of the real contemporaneity of a large number of beds apparently forming distinct series. Of these there are well known examples of great interest not only in the Lake district as already intimated, but also on the borders of Scotland, in Cornwall, in Ireland, and in the Isle of Man. In most of these cases the deposits consist of slates and shales, more or less mingled with sand passing into true greywacke or sandy schists and crystalline slates. The limestones are generally impure, and in lenticular masses or concretions, rarely fossiliferous, or if so, exhibiting only doubtful and imperfect fragments of organic bodies.

979. Silurian rocks having very nearly the same mineral character as those of England are found in various parts of the continent of Europe, in Asia, Africa, America, and Australia. Of these a very large portion of the Older division is found in Northern Europe, where a succession of slates and accumulations of greywacke schist frequently without fossils, or with very doubtful indications of organic existence underlie all the deposits hitherto described. Thus, in Belgium the Ardennes slate is of this kind, and in Bohemia in the east, and Brittany on the west, fossiliferous beds of the oldest period have been distinctly traced.

980. The oldest sedimentary deposits of Russia (those on which St. Petersburgh is situated) are described by Sir R. Murchison as composed of clays, sandstones, limestone, and flagstone; which rest upon gneiss and altered rocks, and, from their position and organic remains, are to be considered the equivalents of the Silurian system of England.

In the blue clay which forms the lowest stratum in the Russian Palæozoic series, no organic remains have yet been found, and the first fossiliferous bed is a sandstone, or grit, distinguished by a remarkable fossil (the *Ungulite*) unknown in Western Europe; but in the overlying limestones, and the flagstones which rest upon them, other organic remains abound, and the subdivisions agree tolerably well, in their leading characters, with those established in our own country.

981. With the exception of trifling dislocations, the Silurian rocks of Russia are so uniformly horizontal that the dip in some places amounts to only 2° or 3°, and in a quarry visited by Sir R. Murchison, its direction was observed by pouring water on the surface of the rocks ; but, notwithstanding this nearly perfect horizontality, there may clearly be traced in the Baltic provinces of Russia a passage from the lowest beds in the north to the higher ones in the south, where they are surmounted by others of still newer date.

The horizontal position of these Russian beds would seem to have been incompatible with any very great thickness ; but the superficial extent to which they may be traced is considerable, and they appear to occupy a tract at least as large as the Principality of Wales. They increase in thickness as they approach the western boundary of the Russian empire and pass into Scandinavia.

982. The Norwegian rocks resemble the lower strata of the English Silurian series in mineral character and fossils. At Christiânia there is a group consisting of dark shale, slate and clay, with calcareous bands and gritstones overlying them, and passing upwards into strata of limestone, which abound in corals, and of sandstone, shale, and conglomerate. The whole series contains fossils identical with those found in the Caradoc sandstone, and the Llandeilo flags ; and Sir Charles Lyell has observed that, at no great distance, there exists a limestone rich in fossils, several species of which were of Upper Silurian types, and others common to both the Upper and Lower Silurian ; he is, therefore, inclined to consider these beds as forming a passage between the lower and upper portions of the Older palæozoic group.

The thickness of the beds in Norway, Sweden, and Gothland is much greater than in Russia, but gradually diminishes towards the junction ; and the rocks lose many of their characteristic fossils.

983. In the south of Europe the remains of rocks of this ancient period are exceedingly rare, but they have been found to exist in the neighbourhood of the Thracian Bosphorus, not far from Constantinople. Mr. Strickland has described from this locality a mass of argillaceous schist (sometimes exhibiting slaty cleavage), compact brown sandstone, and dark blue limestone, all of which pass into one another by insensible gradations. From the nature of the fossils, these rocks seem to be on a parallel with some of the passage beds, uniting the lower with the Upper Silurian groups in Westphalia and Belgium.

984. In North America the older rocks are expanded to a vast extent, and are of great thickness in many districts to the north and west. One group, indeed, of beds of shale, limestone, and marl, in the great valley of the Ohio, is estimated to occupy a surface of 10,000 square miles ; and, by the evidence of fossils, the whole is

referred to the earlier Palæozoic period. These strata are covered by compact limestone and shale of great thickness, and are said to exhibit proofs of contemporaneity with the Ludlow series. Many other parts of North America are remarkable for the extent to which the oldest fossiliferous rocks have been there developed; and the similarity of the organic remains to European fossils communicates an additional interest to the geology of these extensive groups.

Among other remarkable localities may be mentioned the most northerly points (far within the Arctic Circle) reached by voyages of discovery, in tracts where the sea is now frozen during great part of the year. The existence of fossiliferous limestones of the Palæozoic period on the shores of the Icy Sea has been proved by specimens recently brought to this country as ballast.

Even in the extreme south of the great western continent, in Tierra del Fuego, similar phenomena have been observed, and it would appear from recent observations, that the lowest strata in New Holland exhibit fossils very similar to those found in England. These are bedded in a coarse ferruginous sandstone, slightly micaceous, and not at all unlike the greywacke of German geologists.

985. "Great interest attaches to the Palæontology of the Silurians on account of their presenting us with the most ancient forms of organised beings. Representatives of all the great types of life are present in them, but not of all the subdivisions. Of the vertebrata we have only traces of fishes. All the sections of the Mollusca are present, the Cephalopoda and Brachiopoda prevailing; Trilobites are the principal and most characteristic of Crustacea in this formation. Zoophytes are abundant. The Silurians appear to have been deep-sea formations." *

986. Having now arrived at the close of the Older palæozoic period, let us look back upon the collective extent of these deposits considering them in the true order of their formation.

Commencing with the crystalline and altered slates of Cumberland and North Wales, it may be observed that the proportion of argillaceous matter and quartz in these first formed beds is, beyond all comparison, greater, and the mixture with calcareous rocks less, than in strata of more recent date. Although of a thickness amounting to many thousand feet, the vast series of sedimentary deposits forming the assumed base of the Silurian system, may be said to be, almost without exception, composed of clay and siliceous sand, in which the mineral character is constantly apparent; while the presence of mica seems to indicate a preponderance of granitic rocks amongst those to whose degradation and disintegration this long series of crystalline slates, mica-schists, micaceous sandstones, and quartz rock, must be owing.

* E. Forbes in "Physical Atlas."

987. The unvaried character of these beds over large tracts of country, and the general resemblance that obtains everywhere among the oldest sedimentary deposits, has been looked upon as a strong argument in favour of the uniformity of the materials of which the original framework of the solid surface of the globe was composed. It must be remembered, too, that we recognise no such appearance of uniformity in the igneous and altered rocks of more modern date, nor in the metamorphic rocks of the Alps, or other mountain districts, which, indeed, show no indications that can assist us in determining the conditions under which the formation of strata, resembling the Sub-silurian rocks, would be possible. It is the opinion of Professor Sedgwick (whose familiar acquaintance with all the geological phenomena of the lake district, combined with his profound knowledge of crystalline and altered rocks, render him well qualified to offer an opinion), that the abundance of igneous rocks associated with slates of mechanical origin in Cumberland and Westmoreland, and the manner in which they alternate, can only be explained by assuming that outbursts of molten rock were repeated, from time to time, from beneath the bottom of the sea, during the whole period of the formation of many thousand feet of strata. Such a succession of volcanic eruptions, and to such an extent, would seem to be totally unparalleled during the deposit of the secondary strata of our Isles; nor is anything of the kind observable in rocks of still more recent date. It may however appear on further consideration that the chemical condition of these rocks would be better explained by some hypothesis of metamorphic action.

988. At the same time, and while this action was going on, other parts of the ancient seas appear to have been subject to quiet uninterrupted deposits; but in every case the general character of the beds deposited was the same; and even in the rocks which form the base of the Silurian system, where the micaceous and sandy flags contain a few calcareous bands and a moderately large proportion of carbonate of lime, we can easily recognise the materials of decomposed granite, originally formed into beds of gneiss and mica schist and then employed in the composition of these quartzose and micaceous, but sedimentary and fossiliferous, rocks.

989. On the whole, the history of the Older Silurian period may be regarded as one of unquiet and restless agitation and change, but apparently of rapid deposit; and if, in these strata, we do not see the actual rocks first formed by the action of water upon the earth, we are at least introduced to a knowledge of formations more uniform in their character, more extensive in the area over which they are deposited, and of a thickness enormously greater, than is the case with the other and newer Palæozoic formations; and the contrast is still more striking when we bring them into comparison with any

groups of strata formed during the Later secondary, or the Tertiary period.

990. The beds of the Upper Silurian system, from the Lower Wenlock to the Upper Ludlow shales, present, amidst all the disturbances by which they have been affected, an appearance of having been deposited in seas more tranquil on the whole than those of the earlier period ; and they exhibit a distinct lithological character, in which the presence of a considerable quantity of carbonate of lime is a peculiarity, not more strikingly seen in the Silurian strata of England than in the contemporaneous rocks of Sweden and Norway, of Russia, and also of North America. The coralline limestones of this period offer sufficient proof that a change had taken place; although the conditions which governed the duration of species upon the globe, had not yet been brought into action so completely as to efface the marks of the preceding and earliest period.

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991. The systems of disturbing force referred to the Palæozoic period, according to M. Elie de Beaumont's views are four: and although none of them have produced lofty and important mountain chains, they are not without great interest in various parts of Europe. The first in order of time is supposed to have originated between the deposit of the Lower and Upper Silurians, and to have caused the production of the Westmoreland mountains and the Hundsruck chain. The direction of this movement is calculated to have been W. 35° S. by E. 35° N. ; closely approximating therefore that of the Côte d'Or, which occurred between the Oolitic and Greensand periods. This system is recognised in a multitude of localities in the position and structure of many extensive bands of gneiss and clay-slate, and it is called *the System of Westmoreland and the Hundsruck.*

992. The first clear definition of this very ancient elevation, is due to the researches of Professor Sedgwick in Westmoreland. Its recognised range is there very extensive ; as, besides the Westmoreland hills, it comprises the southern range of Scotland, from St. Abbs' Head to the Mull of Galloway, the ridges of the Isle of Man, the slate rocks of Anglesea, mountains in North Wales, and hills in Cornwall. The ridges of the Hundsruck, of the Eifel, and others in Nassau, have, notwithstanding their great obscurity, been referred to this system : but the probability is, especially with regard to the Hundsruck and the Taunus, that these elevations result from a long continued action from below, whose force, as remarked by Professor Sedgwick and Sir R. Murchison, is not yet expended, showing in the hot springs and bubbling fountains of that region, indications of feeble and, perhaps, expiring efforts. These heights, in so far as they belong to the Westmoreland system, must have ori-

ginated previous to the deposition of the Old red sandstone, for the upturned slates pass uniformly under that system, and it seems likewise clear that only the earlier Silurians were disturbed and displaced by the elevating forces. The system is thus, probably, the most ancient of which our globe can now furnish any traces; although, as those disturbed Silurians must themselves have been deposited by the ocean as the *débris* of mountains, we have no ground whatever for regarding even this early dislocation as the first action of interior forces upon the earth's surface. It appears certain, too, that the ranges De Beaumont has included in the group, are but the slenderest fragment of the changes impressed on the globe by the movement in which they originated; for the direction of the upheaved strata (nearly north-east to south-west) coincides with the prevailing direction of the ancient strata, although unaccompanied by mountains in almost every portion of the globe. It is the line along which the old strata of Northern Russia have been dislocated—the great lakes in that region being transverse splits. Captain Bayfield has noticed similar facts in North America; and Humboldt long ago marked the immense extent of the regions manifesting the presence of this line of force.

993. *System of the Ballons in the Vosges, and of the Bocage in Calvados.* — The later Silurian rocks, which show no trace of the previous dislocation, and which must have been deposited at a subsequent period, manifest, in their turn, the action of a force in the direction E. 15° S. to W. 15° N.; and with this disturbance—also prior to the epoch of the Old red sandstone—various mountain ranges, diversely placed, are associated. To these, according to De Beaumont's first views, belong part of the Vosges; the hills of the Bocage; hills in the south of Ireland, and in Devonshire; elevations near Magdeburg; and probably the older part of the Hartz. The direction is nearly constant; inclining, however, towards direct east and west.

994. *System of the North of England.*—From Derby, as far as the frontier of Scotland, a mountain axis intersects the soil of England, running almost directly from north to south, or deviating a little towards north-north-west. The critical discussion of this important range is another of Professor Sedgwick's numerous contributions to the higher departments of English geology; and he has distinctly shown, that while the Carboniferous system has been upheaved, the time of the action of the force must have preceded the deposition of the Lower new red (the Vosges) sandstone. This elevated zone is chiefly remarkable for its immense faults and slips in the raised strata; by means of which its presence can be traced beyond the sphere of its mere mountain ranges. In close connection with it are the rocks which pierce and dislocate the local formations from Shrewsbury as far as Bristol. Nay, that part of the French coast

of the Channel, which runs north and south, intimates, in several ways, that it was originally a fault, occurring during the time of the great North of England elevation."*

995.—*System of Hainault.*—This system, which is rather shown by dislocations than by elevations producing a mountain range, is recognised chiefly in a nearly east and west direction (W. 5° S. by E. 5° N.) across Flanders as far as the western extremity of South Wales. Its date is supposed to have been between some of the deposits of the Permian series, and its results on the coal-measures are too important to be neglected, especially in the smaller coal-fields of Western Europe.

996. The distribution of oceans during the Palæozoic epoch is hardly to be determined from the present state of our knowledge of geology. Still it may be considered as probable that some islands had risen above the water in what is now America. In Africa perhaps a continent existed, or at least three or four large islands now forming the three chains to the south and the first indications of the Atlas chain of Morocco. In Asia from three to five islands might be counted. Palæozoic deposits had separated the North of Europe from its neighbouring continent, and marked out on one side the first contour of the basins of Australia, Hindostan, China, and Siberia; and on the other those of Russia, Scandinavia, Central Europe, the British Islands, France, and Spain. Europe must have exhibited ten or eleven peaks or primitive islands above the surface of those early oceans.† We cannot safely speculate on the position and extent of other land in those wide tracts of ocean which extend over so large a part of both hemispheres.

997. It does not appear possible at present to estimate, even in the roughest manner, the amount of crystalline rock of the epoch we have been considering in this chapter, and no doubt a very large proportion of that which is found now included in such deposits is much more modern than the period itself. The mountain-chains already mentioned, and others that have lifted the Silurian and carboniferous rocks, though not so as to produce distinct ridges, afford ample proof of ancient metamorphoses resembling those of much more recent date; and the condition of some, even of the newer deposits of the period, had certainly undergone change, and been penetrated with dykes of crystalline rock even before the close of the Palæozoic epoch.

998. The views of the older geologists with regard to the antiquity of crystalline rock, and especially of certain kinds of granite, can hardly now be received even to the moderate extent to which some French writers have recently advocated them, for there is nothing in the granites and protogine of Mont Blanc or other parts of the Alpine chain which indicates modern date; and yet there

* "Physical Atlas," C. 2, p. 7. † Ibid. p. 8.

seems no question that the whole of the Alpine chain without exception was still below the level of the sea at the termination of the deposit of the chalk, and even during the accumulations of Tertiary rocks contemporaneous with our London clay. So completely is this the case, and so much of the porphyritic rocks occupying the most prominent place amongst existing deposits is clearly traceable to comparatively recent epochs, that there is some difficulty in producing evidence of the very existence of that really ancient granite which has been described and often regarded as the very skeleton and ground-work of the earth.

999. But that large quantities of crystalline rock, as granite and gneiss, did belong to the Palæozoic period is proved not only from the appearance of such rocks thrust through some of the most ancient deposits and not disturbing others that are more recent, but from the presence of numerous fragments even in the earliest Silurian rocks obtained certainly from these sources. The presence of mica and other materials of granite in old rocks might also have suggested this, and some gravels even are known whose origin must apparently be sought for so far back in the earth's history as the early part of the most ancient epoch. It would no doubt be in the highest degree interesting and satisfactory to discover also some mineralogical character which could mark at once the age of crystalline rocks; but of this there is no present probability, and we must be contented to wait for other evidence less manifest if not less satisfactory.

1000. "No doubt, as M. de Beaumont has observed, granitic eruptions have become more rare in the more recent epochs, and doubtless it is most true that in the Newer secondary and Older tertiary formations the granitic rocks become more and more exceptional; but had we lived in the Carboniferous or Permian epochs we might, I conceive, with equal justice have declared the only granites then visible to be extremely ancient. The more quartziferous varieties, together with a certain class of metalliferous veins, posterior in date to the vegetation of the coal period, such as are now known to the miners of Cornwall or to those of the Ural Mountains, would then have been unformed, or at least invisible. The ages which have elapsed since the coal-measures were accumulated are so countless as to have afforded ample time for the upheaval of much crystalline rock and metallic ores from great depths, and for the clearing away of superficial matter by aqueous denudation. To what an extent this subsequent denudation has been carried may be shown by adverting to the fact that the masses removed must have more than equalled in volume all the sedimentary strata newer than the coal, for some part of the materials of such strata have been more than once ground down into sand or mud since that period and re-stratified."*

* Sir C. Lyell. Anniversary Address to Geol. Soc. for 1850, p. 43.

1001. In bringing to a conclusion this division of our subject let us now recapitulate briefly those facts and groups of facts that have passed in review before us, and endeavour thus to make out the final results of geological investigation.

In the first place, we find that the whole crust of the earth is now, and probably always has been, exposed to the action of certain forces, producing a change in its physical condition. One of these forces is almost exclusively superficial, and acts by wearing away gradually but steadily every prominence above the water-level, and depositing each particle in regular order, and ultimately at the sea-bottom. The oldest rocks as well as the newest exhibit the daily and hourly action of such causes, while the newest as well as the oldest speak of occasional and far more extensive, but paroxysmal action of somewhat similar nature. Almost all the members of the extensive series of stratified rocks have thus been formed, so that we might have expected, if only these causes had been in action, that there would either be by this time no inequalities left, or that they were originally so vast as to have resisted hitherto such energetic and persevering attacks.

1002. Neither of these, however, is the case. Besides this action of water, there is a counter-action going on beneath the surface connected with the influence of heat. Perhaps there is not one spot on the whole surface of the earth that is not at this moment, and that has not been since its first existence, in a state of movement, oscillating up or down. Every fresh observation tends to render this more probable, and undulations of this kind, sometimes amounting only to a few inches in a year, influence and greatly modify the result of aqueous action. Besides slow movements of this kind there are, however, other and more manifest changes, and in the neighbourhood of a volcano there are generally proofs of greater intensity of subterranean action.

1003. Starting with these ideas of the moving forces employed, and commencing with the older rocks, we find them to consist of thick deposits of mud and sand, with limestone, indicating the existence of a broad expanse of open sea, subject perhaps to great temporary changes of level, and therefore to considerable movement, and containing a multitude of marine animals, almost exclusively shell-fish of various kinds, uniform, or very nearly so, over considerable tracts, and exhibiting no marks whatever of the vicinity of land. To this condition of the sea there succeeded another, in which fishes of very extraordinary form, and totally different from existing species, were introduced in great variety and abundance, and flourished not so much perhaps in the deep sea as in the neighbourhood of a coast line then being lifted up above the waters. There was, perhaps, very little land in any part of the north temperate zone at the period we are now discussing.

The elevation in progress during this middle part of the older period seems to have been succeeded first by a period of depression, during which coral reefs were built, and then by another elevation, until a number of islands were formed, and became clothed with a rich and luxuriant vegetation of ferns, palms, and other trees of singular forms, long since extinct. Perhaps it may explain the condition of this older period if we consider that the whole of the latter part of it was one of disturbance and rapid undulation of surface, admitting of the deposition of those numerous beds of vegetable matter, which have been since converted into coal.

The termination of the period during which fishes had become of larger size and more abundant than before, was marked by many disturbances, producing fracture of the beds, but the disturbances certainly produced their chief effect after the consolidation of the strata and the formation of true coal from the vegetable matter deposited.

1004. We come next to the Secondary or Middle period. A very long interval indeed must have elapsed between the deposit of coal and the overlying sandstones, and the Upper new red sandstones, which we find horizontally bedded, and reposing unconformably in the upturned edges of the older rocks. During this period there occurred a total change of the inhabitants of the sea.

In the newer beds we find abundant fossil remains referable to various animals, including many singular and gigantic reptiles, some of them constantly inhabiting the sea, and most of them highly carnivorous, but some organised not merely to live on shore but on vegetable food, and expressly adapted for conditions resembling those under which the hippopotamus, rhinoceros, and elephant exist. Besides these marine and terrestrial reptiles we have, however, a third group, representing the birds, and proving how perfectly animals having all the typical peculiarities of the most highly organised class, though the lowest of that class, could be adapted to exist not only on land and in the sea, but also in the air. With these animals we find—although they are very sparingly distributed — indications of the existence of quadrupeds and birds, and from time to time such other evidence of land, that we may be certain of there having been a considerable elevation of the sea-bottom since the deposit of the sandy beds which repose directly on the coal. Still there are, so far as we can tell, no marks of an extensive tract of land in any way resembling that which now exists in the northern hemisphere. The land during this period was probably distributed in a totally different manner, being certainly adapted for races of animals distinct, not only in general form but in many details of structure, from those which have since replaced, or which now represent them.

The land, however, probably increased on the whole, rather than diminished in these latitudes, during the deposit of the Oolitic rocks, and towards the close there was formed that enormous mass of freshwater or estuary origin, which we find in the South-east of England, and which geologists denominate *Wealden*. This, however, was followed by a depression, at first, perhaps, alternating with elevations, but soon increasing and becoming considerable, while a multitude of marine animals secreted enormous quantities of calcareous matter, and deposited it at the sea-bottom, in the beds which have since become chalk. The animals whose remains occur in chalk, are chiefly those which require deep water, and the very considerable area over which they are uniformly spread renders it probable that the circumstances throughout were similar.

1005. At length, but not till after a very long interval, the vast ocean-floor was broken up, and outbursts of lava hardened and partly covered the chalk of the North of Ireland, and extended to the islands of Scotland. Similar eruptions produced analogous effects elsewhere, while a great line of intense subterranean action lifted up the beds in the South of England, gave the prevailing direction to the Pyrenees, the Alps, and the Carpathians, and produced, perhaps, a very extensive tract of dry land on the southern side, and a few islands on the north.

1006. About the same time, or not long afterwards, the elevation of the Himalayans commenced, producing a somewhat similar tract, but between the two, in Egypt and in Western India, there seems to have been a deep sea. From this time elevation and depression must have both gone on over parts of Europe and Asia on an extensive scale, the land that extended westwards and southwards sinking down rapidly, while Northern Europe became nearly covered with an extensive open but shallow sea, in which were deposited the sandy and muddy beds of the great existing river-valleys. Afterwards, elevation again took place, and the existing physical features of Europe were produced; and while the greater part not only of Europe but of Northern Asia, was the resort of innumerable herds of elephants and large cervine animals, the swamps and marshes were the abode of rhinoceroses and hippopotamuses, numerous lions and tigers roaming about the forests and plains, associated with hyænas and bears. After this, there was a continuation of the elevating process towards the north pole, and a great extension of land in that direction, so that an almost icy sea extended down nearly to the central countries of Europe, and enormous icebergs floated over a great part of the existing land, there depositing the gravel which had been removed from distant spots, and was often collected from more than one locality. Another elevation of this part, and a corresponding depression northward, again changed the inhabitants

and the whole coast line; and, probably, the present distribution of land was the result. Lastly, we have, now going on, an elevation in Northern Europe and a depression in our own latitudes, the result of which will be to lower the mean annual temperature, although it may possibly be that the climate will become more equalised in consequence of the slight depressions of the general level.

1007. Such, then, are some of the results of geological investigation with regard to the changes that have taken place on the earth's crust and the successive races that have been its tenants. Exhibiting results so important, Descriptive Geology cannot now be looked upon as a subject only fit to be argued and discussed, but must be carefully studied. It is a distinct and important pursuit; its problems involve the highest and most philosophical views of general Natural History, and of the application of mathematical science. Its conclusions are sound and permanent, and its object simple and definite. The Geologist takes up every branch of descriptive Natural History, and suggests the laws by which the most obscure of Nature's operations have been conducted. He makes observations by which the truth of such laws must be tested, and he accounts satisfactorily for a multitude of natural phenomena not otherwise to be explained, giving, in fact, a true and connected history, not only of the earth itself, but of events that have taken place upon and beneath its surface, and that have influenced its progress towards the condition in which we now see and study its surface.

And it cannot be that such a history should be known and not produce important results with regard to those operations that are carried on by man either upon the earth or in the deep recesses to which he is able to penetrate. As all such operations necessarily and immediately depend on the structure and contents of the solid crust exposed for our investigation, a knowledge of the laws according to which the various parts of that crust have been originally formed and since modified is in the highest degree important. Geology is no less needed by the engineer and the miner than astronomy is by the mariner. All calculations must be made, all new works undertaken, and all old ones continued, in accordance with what is believed to be the structure of rocks, and a knowledge of structure is obtained only by geological investigation.

PART IV.

PRACTICAL GEOLOGY.

CHAPTER XVIII.

ON THE APPLICATION OF GEOLOGY TO AGRICULTURE, ENGINEERING, AND ARCHITECTURE.

1008. If the Reader has made himself acquainted with the facts of Geology, or in other words, if he understands the nature of the materials of which the earth's crust is made up, the order of arrangement of those materials, and the changes undergone both in the actual rocks themselves, and in the position they occupy, he will not be inclined to question the value of such knowledge to practical men; or the nature of the applications of Geology to practical purposes. Such knowledge must always be available when any thing is undertaken concerning the earth, either as the basis of operations, or the source whence all valuable materials are obtained. It may be well, however, to illustrate this point by a few simple examples.

1009. Regarding the earth first as the basis of operations, it is well known to every engineer that the whole management of earthworks, whether for roads or intrenchments, whether in cuttings, tunnelling, or embankments, must be greatly influenced by the nature of the soil, the subsoil, and the underlying rocks; the latter directly modifying the former, and being the original and fundamental cause of all peculiarities of condition. The permanence of any structure also must, in like manner, depend on the rock in or on which the foundation is placed, and thus requires a consideration of geological position; while questions of drainage and the source of water supply, both for the use of towns and in agricultural districts, directly depend on the geological constitution of each locality, since without reference to so essential a point the principles of science concerning these matters cannot properly be applied. It is only

within a few years perhaps that such an application has been made, but the numerous reports concerning the drainage of towns that have lately appeared, show at once the admitted necessity of something of the kind; and in too many cases they have afforded examples of the want of an acquaintance with the first principles of Geology on the part of the engineer.

1010. As to material again, it is clear that all substances derived from the earth should be studied, at least in some measure, in the place where they occur in a natural state; and no one is really capable of judging concerning the value of material without knowing something of its history. This applies to agriculturists, who should know whence soils are derived, and where to look for desirable rocks for mingling with others at the surface:—to land-valuers, who ought to be well acquainted with the causes of improvement or deterioration that may be at hand to affect the value of the property they estimate:—to builders, who require to select the material afterwards to be used for buildings:—to architects and engineers, who arrange plans dependent for success on the nature of the ground and that which is beneath it, and its reference to the structure to be erected upon it: and above all to miners, whose business is chiefly confined to rocks generally concealed, and who most of all require a knowledge of laws and conditions, of facts and inferences, concerning the materials of which the earth is constructed, and the circumstances under which these materials are generally present.

1011. The facts of Geology which are most important to be known are chiefly these which relate to structure, involving the mechanical condition, the chemical composition, and the mechanical position of rocks. These are all points which must be learnt, not only by reading and description, but to some extent by actual personal knowledge; and no acquaintance with Geology is useful which is not based on actual observation and investigation. A single real attempt, however apparently unsuccessful, to map a country geologically, and draw a section that shall explain the map, will be of more value than any amount of knowledge of what other people have effected. Without books, however, to enable the student to set out in the right direction, but little progress is made, and mistakes are inevitable.

1012. Although the facts of Geology have been mentioned at some length in preceding chapters, it may be well to recapitulate a few of them here very briefly. Thus the first series, those of mechanical condition, are taught by the natural history definitions of rocks, and may be described as including their hardness or softness; brittleness or toughness; permeability or impermeability to water; their composition as simple rocks, as limestones; or compound rocks, as marls and conglomerates; their texture, whether fine or

coarse, compact or loose, crystalline or massive; and their specific gravity: — these all being points which may be considered as mechanical, with reference to masses of rock.

1013. The facts of chemical composition are also important and varied. They include a knowledge not only of the prevailing simple mineral, but the associated minerals; the way in which the minerals are combined and modified; the probability of disintegration and decomposition under exposure of certain kinds; and the degree of metamorphic action that rocks have undergone or are undergoing.

1014. The facts of mechanical position involve the actual position of stratified masses with respect to the horizon, with respect to other strata, and with respect to crystalline and unstratified masses. These are known when the dip and strike, the nature and position of the anticlinal and synclinal axes, the systems of faults, and the various discordances of stratification in a district, are fully made out. All these facts are learnt by observation; they are quite independent of any controverted points; they offer, perhaps, little of the romance of Geology to the general reader, but they come home to every-day life, and no man can be an engineer or a miner, none can safely pursue agriculture, or rightly carry out sanitary principles in the construction of a house, a public building, or a town, without knowing them and acting upon them.

1015. The object in this and the subsequent chapter is merely to give a very brief and general outline of the application of these facts. The subject admits of much more extended treatment, and the author has it in view to prepare a more complete and useful system of Practical Geology. He has already, in a former work,* entered at some length on various points of interest connected with it, and here only introduces it as an essential part of an outline of Geology, and as affording opportunity for a statement of the plan he thinks it advisable to adopt.

1. *Agricultural Geology.*

1016. The formation of soils is a subject of great interest in connection with geological structure, and can only be properly understood by reference to the action of the atmosphere and water in producing the disintegration and decomposition of various rocks, together with a due consideration of the way in which a vegetable soil is derived from a subsoil containing no vegetable ingredients and this latter from a rock. In many cases the sources whence the peculiar properties of a soil are derived, and whether these are favourable or unfavourable to vegetation, is by no means manifest, and instances not unfrequently occur where knowledge of this kind would be exceedingly and immediately useful.

1017. A geological map represents, by systems of colours, a number of geological facts concerning the rocks of a certain district or

* Ansted's "Geology," 2 vols. 1844.

country, and it is very important to remember, that it neither does nor professes more than this. It does not, for example, give any account of the mechanical condition or the chemical composition of rocks, and no complete account, in most cases, even of the details of mechanical position; still less does it indicate the nature of the subsoil or decomposed rock overlying the principal mass; and least of all does it give any idea of the nature of the soil. Combined with sections, it teaches something more concerning the magnitude of the rocks and their mechanical position, and perhaps something of the thickness of the overlying soil and subsoil, and with the accompanying description, if there is one, the actual nature of the rocks is mentioned. It may seem from this account that to the agriculturist such a map would be either useless or mischievous, either teaching him nothing or telling a falsehood, for he has only or chiefly to do with the surface, and cannot understand that he may have a tough clay soil where the map marks "oolite;" a loose sand, where he is led to expect "London clay;" a rich grey marl in the "old red sandstone," or other similar anomalies. Still he must not suppose that the map is without its use. The names, perhaps, are unfortunate, as being only locally descriptive, but the story told is true and exceedingly useful when understood, for it really enables the practical man to discover readily what he ought to know, and is highly suggestive with regard to the most important facts that bear upon surface operations.

1018. In a former chapter an account has been given of the component parts and structure of rocks, and it is quite certain that in most cases the subsoil is immediately, and the soil intermediately, derived from the decomposition of the subjacent rock, so that the fertility of land depends on geological structure. It would, also, be easy to show that, by taking advantage of the presence of certain mineral substances beneath the surface, a soil naturally barren may often be rendered fertile. The whole subject of mineral manures consists in the proper employment of such substances as may counteract the injurious qualities of a barren or poor soil, and either supply the want of some indispensable element of the plant to be cultivated, or prepare the soil to receive those atmospheric influences which are essential to the development of vegetable life.

1019. There are two modes in which derivation from another rock may be traced; for sometimes a soil consists of nothing more than the minutely divided particles of one simple rock, as sand, while in other examples the soil exhibits an admixture of carbon, and of various mineral substances not easily traceable. It not unfrequently happens that rain, penetrating the minute surface-crevices of an exposed rock, aided by frost, crumbles down the hardest materials, and, if these crumbled portions are washed away, they are

rapidly succeeded by others, so that a soil is formed, which at length, under favourable circumstances, becomes covered by mosses and lichens, from whose decay is obtained that supply of carbon and other materials which in process of time renders the soil fit for the growth of other vegetables which are useful to man.*

1020. The dependence of a soil on the underlying rock extends even to its colour, which is white in chalky soils, red on the New red sandstone and the ochraceous beds of the Greensand, and yellow on the clays and clay-slate, &c.: but it will not be expected that these conditions should hold when there is a thick bed of superficial detritus, such as gravel; for the gravel must then be looked upon as the parent rock, and the condition of the soil will be influenced by the actual underlying bed.

1021. There are one or two general principles with regard to this part of the subject, which it may be worth while here to enunciate, but which it will not be necessary to enlarge upon or illustrate.

The *depth* of a soil is chiefly dependent on the nature of the subjacent rock, and on its ready decomposability by atmospheric agents.

The *texture* of a soil also depends on the parent rock, as to whether it shall be loose and gritty, or tough and clayey, and varies according to the tendency of the rock to decompose and the manner in which it is affected by decomposition.

The *fertility* of a soil depends partly on its depth and texture, and partly on its possessing those mineral constituents which enter into the structure of the plants to be grown upon it.

The *use* of the soil in enabling plants to grow is twofold: first mechanical, the soil affording the plant a firm foundation, and enabling its roots to take up certain quantities of organic and inorganic substances necessary for its nutriment; and secondly chemical, inasmuch as all plants, without exception, possess a certain amount of inorganic as well as organic constituents, which after undergoing decomposition and entering into new combinations are taken up from the soil, and assimilated for the use of the living vegetable. These substances are required also to be present in the soil in such a state that the roots of the plants are able to absorb them.

1022. Liebig states it as distinctly proved, in analyses made by De Saussure and Berthier, that the nature of a soil exercises a decided influence on the quantity of the different metallic oxides contained in the plants which grow upon it,† but it does not follow thence that the actual quantity of alkaline bases varies; and it appears, on the contrary, from other investigations, that the total amount of oxygen united to these bases is always the same in the same plant, and therefore that the proper quantity of some of them as bases is essentially necessary; the growth of the plant being arrested when these substances are wanting, and much impeded when they are deficient.

The alkalies are often supplied to the soil by rain-water, where they are certainly present, although it is not known in what form they exist. Besides these mineral substances, and some others, the

* The amount of organic matter required to give fertility to a soil varies from three to ten per cent.

† Organic Chemistry, p. 95.

presence of carbon is absolutely necessary, as before-mentioned; and the action of the weather, the absorption of rain-water, and, above all, the chemical changes constantly going on in the process of gradual oxidation (the oxygen being obtained from the atmosphere), effect the necessary alterations in the different constituents of the soil, and render it fit to support vegetable life.

1023. Some plants, as the grasses, require a considerable quantity of silex for their proper growth and nourishment; and this, which is chiefly present in the stalk, is supplied in the form of silicate of potash. But the grasses also require phosphate of magnesia, which is an invariable constituent of their seeds; and thus the presence of phosphorus, potash, silica, and magnesia in the soil is absolutely necessary for the proper growth and ripening of a crop of wheat. Other plants possess other salts and alkaline bases, and in different proportions, and all these substances require to be presented to the roots of the vegetable in the most convenient form for absorption.

1024. It will now be seen in what way the soil acts, and how far vegetation depends on the actual materials of which the soil is composed. If any of the constituent parts are wanting, they may usually be supplied at no very great distance, and it is chiefly such soils as do not suffer decomposition that are necessarily and hopelessly barren; but these are so few, that they need hardly be the subject of consideration.

Perhaps one of the most common examples of an ordinary barren soil is that in which the soil is composed of silex, either pure and in the form of compact rock, or made up of loose grains of sand, mingled only with a certain proportion of alumina and oxide of iron not sufficient to admit of the ready growth of plants. Such soils as this are to be found on some parts of the coast of Flanders; they occupy also the tops of some hills and mountains of igneous origin, and they certainly offer no prospect of return for labour bestowed upon them in such situations. But in the interior of a country where heath and furze once plant themselves and flourish, although there may be at first little prospect of success to the agriculturist, the case is by no means hopeless; and the vicinity of clay might often be taken advantage of to bring these districts into profitable cultivation. The alumina and lime in such case may be supplied artificially, and the other constituents may often be obtained from the decayed and decomposed plants which have grown upon the spot. It is unnecessary to say that sandy beds allow the moisture to traverse them very readily, and are soon heated, so that the crops grown upon them suffer greatly from drought. This must be to a certain extent unavoidable.

1025. Stiff clay, unmixed with a sufficient quantity of silica in the form of loose sand, is sometimes extremely difficult and troublesome to bring into cultivation. The chief want here to be supplied is that of lime; for there is always abundance of silex, although not in the best or most convenient form. The stiffest clayey beds,

when dressed with lime, are readily made to bear valuable crops; but, as the clay is exceedingly retentive of water, and yields it back to the atmosphere with great difficulty and very slowly, it is often necessary that artificial drainage should accompany whatever other method may be adopted for the bringing such soils into cultivation. The agency of frost in breaking up stiff clays is often of great importance.

1026. Limestone, when pure, or nearly pure, as in the state of chalk or crystalline limestone, is often a barren rock; and this is especially the case when it is exposed on a hill-top, where the rain is unable to transport argillaceous portions from adjacent clayey beds. An admixture of clay, however, converts decomposed limestone or chalk into marl, and in this state it becomes an admirable soil. Magnesia is also a very common, and almost necessary, constituent of soils to a certain small extent.

1027. It is worth while remarking here, that the lime and magnesia, as well as the potash and soda found in soils, are all of great importance, and form bases which, when mixed with oxygen are in a condition to be absorbed by plants to whose growth they are essential. None of these earths however alone, nor indeed any two of them, even when associated with carbon, are sufficient to form a productive soil; and, besides being mingled in the proper proportions, it is necessary also that the mixture should possess a proper texture, adjusted to the quantity of rain that is likely to fall; for without this the air is not properly supplied to the root of the plant, and the process of oxidation, effected during the slow decomposition of this air, and upon which the growth of the plant seems to depend, does not commence, so that the plant is either parched for want of moisture, or stifled for want of air. As a general rule, it has been noticed that more rain falls on mountainous districts than in plains; and this exactly answers to the usual position of clayey soils in plains and valleys, and a freer and more open soil on the high ground.

1028. With regard to the relative value of different geological formations in agriculture, no general rules can be laid down; and as it is rather the mineral and physical character than the geological age, the determination of which is important, the Geologist can only bring his knowledge to bear in any given instance when he has informed himself of the actual structure of the district.

1029. Before concluding this subject it is right to add a few remarks on the determination of the value of land, and the advantage of an adequate knowledge of Geology in attaining this result.

Where an estate is situated on several beds cropping out in succession, and of different agricultural value, a person ignorant of Geology would be greatly puzzled to determine the value of the estate; and it would present appearances extremely different if the surveyor first walked across it in the direction of the dip, and afterwards on the strike.

In order to obtain a true notion of the value, subdivisions of the property must be made, and the arranging these would be greatly facilitated by knowing the lines of out-crop of the different strata.

But, besides enabling the land-agent to do this, and to identify the various soils with the general productiveness of which in other places he should be acquainted, Geology would point out what land is in a forced, exhausted, or ordinary state of cultivation; while from the mineral structure of the subjacent rock the composition of the soil may be inferred, and any substance detrimental or favourable to vegetation be detected.

1030. "A surveyor, therefore, should be acquainted with the nature and extent of the geological formations, especially those in the more immediate sphere of his duties; and in acquiring, as well as applying this knowledge, he would be much aided by good geological maps. He should, also, make himself thoroughly acquainted with the relative productiveness of the soils on these formations; and in valuing an estate, he should observe the texture of the soil and subsoil,—the dip and compactness of the strata,—and the form of the surface of the land; all these circumstances greatly affecting the value of landed property."*

2. *Drainage.*

1031. Drainage is, in many important respects, a truly agricultural subject, for no land can be well cultivated which is not properly drained, and no drainage can be properly effected without some reference to the geological structure of the district.

The drainage of an island or continent is effected, under ordinary circumstances, by means of a gradual and usually gentle inclination of the surface of the country towards a river-valley, a lake, or a coast-line. The rain which falls on the various parts being conducted by channels, or rushing down the hill-sides into brooks, is by them conveyed to the neighbouring rivers, and these, descending into and traversing the plains, at length reach the sea; the rate of motion of the waters in all these channels necessarily depending on the amount of the fall, and the relation it bears to the distance traversed during the whole course of the stream from the high ground to the sea.

1032. Now there are two points in this statement which deserve attention, namely,—first, that the rate of motion, or the velocity of the current, has reference to the distance traversed, as well as the amount of fall; and next, that after the water has been conducted to the foot of the hills, on whose surface it has been partly collected, it frequently has to traverse a large extent of country nearly horizontal, or in which the descent towards the sea is hardly appreciable. Both these points must be evident to every one who considers the subject; for the latter is simply a statement of fact, which may be verified by referring to almost any map; and the former is equally clear; for if a river has to traverse a certain tract of country in a direct line to

* "Whitley's Application of Geology to Agriculture," p. 143.

the sea, with a given amount of fall,—then if the distance traversed is increased by means of the sinuosities of the channel through which the water is obliged to pass, the rate of motion must evidently be diminished.

1033. In those cases in which an extensive tract of nearly flat land (its elevation not being much above the level of high-water) is traversed by a number of streams, nearly stagnant for want of a sufficient fall to carry off the water, there is an evident tendency to form swampy and marsh land, and the slightest accident may at any time produce this result, and lay under water a whole district.

1034. But there are other cases of a totally different kind, in which the long continuance of moisture on the soil is exceedingly injurious, and prevents cultivation. Among the most remarkable of these must be ranked those numerous instances of peat-bog which are so common in Ireland and in many other countries, where the water is retained partly or entirely beneath a thick tough coating of vegetable soil, made up of the matted roots of plants. The drainage of bogs in this condition requires, as may be supposed, a process quite different from that which would succeed with fen-lands; and most of the cases in which it is required to improve land by drainage will be found to refer either to the class just described, or to that of which the fens offer the best example.

1035. The very fact of stratification itself, and the manner in which the subsoil and the soil are derived by decomposition from the underlying rock, afford a ready explanation of the well-drained condition of the soil in any district that is tolerably fertile. Drainage is indeed a natural result of the existence of alternating strata of different materials, some (as sandy beds) allowing water to penetrate them freely, others (as the clays) resisting its passage, and others again (as many limestones) admitting the water by numerous cracks and fissures into reservoirs and subterraneous caverns, but not absorbing it except near the place of contact, and remaining elsewhere comparatively dry and unchanged.

1036. All these different beds occurring at intervals, and being covered up by the subsoil, which rarely resists the passage of water through it, the surface-water, when in excess, penetrates into the subsoil, and is thence carried down till it reaches a permeable stratum, where it is absorbed and swallowed up, unless, indeed, as sometimes happens, this bed is already sufficiently loaded with water, and can no longer receive it. There are thus two very different conditions under which the natural soil of a district may be rendered infertile by the presence of stagnant water, and in like manner there are two ways in which drainage may be effected, the one of which is called surface and the other deep-draining. By the former is meant the carrying off the water by drains cut upon the surface, while the lat-

ter depends rather upon the geological condition of the underlying rock.

1037. Besides the ordinary conditions of stratified rocks, the faults, or results of the disturbances of strata, may also occasionally assist the agriculturist in the drainage of land, for some of these faults are pervious to water, and act as main drains to large portions of country, while others, again, are filled with clay, and keep in the water on one side of the fault, preventing its passage to the other. In either case advantage may often be taken of the fault by any one possessed of an adequate knowledge of Geology.

1038. As a fit conclusion to this part of the subject, in which drainage has been considered as connected with agriculture, there are added here some interesting remarks by Mr. Johnston, abstracted from his Lectures on Agricultural Chemistry (p. 440).

The advantages of drainage to the agriculturist are numerous and manifest. In the first place it carries away rapidly the superfluous moisture, moderates the natural dampness of the climate in a wet, boggy country, and is equivalent, therefore, not only to a change of soil, but also to a change of climate, both with reference to the growth of plants and the health of the population.

Drainage produces, also, the effect of an actual deepening of the soil, as it facilitates deep ploughing, and permits a greater absorption of useful moisture, and useful mineral salts, or organic matter, while it is also the means of noxious mineral compounds, such as the salts of iron, being diffused equally and harmlessly through the soil, or carried away before they have time to form those ferruginous compounds which are injurious as an impervious subsoil.

Drainage also alters the direction of the currents which occur in wet soils, the roots of plants obtaining their moisture from the rain which falls on the surface in drained lands, whereas in deep swampy ground, their spongioles are only supplied with exhausted subsoil water.

Lastly, it is a necessary preparation to many other means of improvement which may be applied to land, and must in all cases be preliminary to every kind of building and engineering work, as no foundation can be stable, and no situation good, in which the water is allowed to remain and accumulate on a retentive soil.

1039. The process of deep draining differs from that of surface-draining already described, and has for its object a somewhat different result. It is also connected with the subject of road and canal-making, and requires to be understood and carefully attended to by the engineer, for without such attention a canal may be useless, after all the expense of construction has been incurred ; and a line of road may be so dangerous as seriously to interfere with the traffic upon it.

1040. In the case of road-cuttings, and especially deep cuttings for railways, and also in tunnelling and shaft-sinking, a familiar acquaintance with the principles of Geology, and a knowledge of the structure of the earth may be, and of late years often have been, of very essential advantage. Where bands of sand, or any soluble or easily-moved material, are crossed by such cuttings, and contain or transmit water, the position of the outcrop requires to be known to prevent mischief from slips, and in all cases the slopes of a cutting should be formed with reference to the dip of the strata, especially when the cutting is at all in the direction of their strike.

1041. The importance of geological knowledge in canal-making was long ago recognised, and was applied by Mr. W. Smith, in 1811, in a very successful manner. About that time many canals were being cut in the West of England, and these, crossing the Oolitic hills, were found to be particularly liable to accidents of leakage, being cut through open-jointed, and sometimes cavernous rocks, alternating with water-tight clays. In the passage across the former rocks, and more especially when the summit level of the canal occurs in them, the water escapes almost as fast as it enters, and all the skill of the engineer in puddling, and making an artificial bed, is sometimes exerted in vain, and cannot prevent great and ruinous loss. But the existence of open joints and caverns is by no means the only, nor, indeed, is it the greatest source of injury, for innumerable small faults or slides traverse the country and confuse the natural direction of the springs, rendering them short in their courses, and uncertain and temporary in their flow, weakening, by their irregular pressure every defence that may be opposed to them, and causing leaks, which let through a portion of the water contained in that level of the canal.

1042. The general remedy for all these evils was understood by Mr. Smith, and proposed by him for adoption. It is "the entire interception of all the springs which rise from a level above the canal and pass below it through natural fissures and cavities. This is a process requiring great skill and extensive experience; some of the springs, for instance, which it is most important to intercept come not to the surface at all in the ground above the canal, but flowing naturally below the surface through shaken or faulty ground, or along masses of displaced rock which extend in long ribs from the brows down into the vale, emerge or attempt to emerge in the banks of the canal; these no ordinary surface-draining will reach, and none but a draining-engineer, well versed in the knowledge of strata, can successfully cope with such mysterious enemies. But Mr. Smith, confident in his great experience, not only proposed, by a general system of subterraneous excavation to intercept all these springs, and destroy their power to injure the canal, but further, to

regulate and equalize their discharge, so as to render them a positive benefit. This he would have accomplished by penning up the water in particular natural areas, or pounds, which really exist between lines of fault in most districts, or between certain ridges of clay ('horses,') which interrupt the continuity of the rock, and divide the subterranean water-fields into limited districts, separately manageable for the advantage of man by the skilful adaptation of science."*

1043. This account of the nature of the work required in subterranean drainage is so much to the purpose that I need add little further in illustration of the subject. The principles involved must in most cases be nearly the same, and whether it is required to prevent a canal from leaking, or a deep cutting or tunnel from being drowned, or whether, finally, it is the object to prevent that washing away of a thin intermediate stratum, by the absence of which an upper bed will be enabled to slide upon a lower one and produce a landslip, the general nature of the contrivances to be adopted differs but little, although the particular method must in all cases be strictly adapted to the special conditions involved, and must vary in every district. It is only by a clear and accurate comprehension of the actual cause in each instance, that the draining-engineer can hope to succeed, whether in combating an evil that already exists, or preventing an accident that is foreseen.

3. *On Water-supply from Rocks.*

1044. The distribution of water within the crust of the earth, is a subject of very great interest to the engineer and miner, and not less so to the agriculturist, while the condition in which water is present in the earth, the substances held in solution or suspension, and the circumstances under which it can be extracted, are questions worthy of the closest and most careful consideration, with reference to the supply of water to towns for household and sanitary purposes.

1045. The atmosphere is well known to be the main agent employed by Nature in the distribution of moisture upon the earth, absorbing a considerable quantity of water in its passage over the sea, and afterwards depositing it in the form of rain, owing to changes which take place in its temperature, and, probably, in its electrical condition. Of the quantity of rain, however, which falls upon the earth in a given spot, only a small proportion finds its way to the sea directly and immediately, by means of rivers; and it has been calculated by M. Arago that this proportion in the valley of the Seine is not more than one-third. Of the rest, some portion is, no doubt, re-absorbed by the atmosphere, and some enters immediately into the composition of plants and animals; but a large quantity remains,

* Phillips' Life of William Smith, p. 69.

and this descends into the bowels of the earth by means of those strata which are permeable to water, and it is either retained in them until they are full, and then poured over their edges into the neighbouring country, to feed the nearest stream; or is discharged in the form of perennial springs, where the containing stratum is exposed on a hill-side; or, lastly, is accumulated in the substance of the rock or in reservoirs, whence it is discharged by some natural or artificial communication being made to the surface at a lower level.

1046. Rocks, however, vary greatly in the quantity of water they retain, in the way in which they retain it, in the relative facility with which they absorb or part with it, and in the degree of accidental interruption that can interfere with the free course of the water beneath the surface. Thus sands, if loose, allow water to percolate freely through them; if hardened, they conduct water very badly, or not at all; if broken, they offer natural channels, permitting a very perfect but partial transmission. So limestones, under certain circumstances, are good conductors; and, under other circumstances, very bad conductors of water: and this is governed by the nature of the rock, its condition, its position, and generally by those facts observed and described by the Geologist. Even clays, although generally tough and quite impermeable, retaining water to any extent, are sometimes broken by permeable joints, and sometimes are mixed with so much sand and lime as not to be absolutely close.

1047. Few experiments appear to have been made with reference to this very important subject. All rocks indeed are known to contain water; and, so general is this, that many ignorant or half informed persons, think it only necessary to bore to some depth beneath the surface in any spot in order to discover a spring. The frequent disappointments in such cases afford proof of the necessity of using some judgment in the matter; but the more frequent success, however partial, affords the best evidence of the presence of water generally at all moderate depths beneath the surface. It is of the utmost importance to know, as far as possible, the condition of various rocks in this respect.

1048. Natural springs occur (1) in surface-rocks of loose and open texture, as sand and gravel fully saturated with water, and not covered by impermeable beds:—these are called land-springs, and cannot rise above the surface; (2) at the outcrop or intersection of fully saturated permeable beds lying between beds more or less impermeable:—these are not uncommon, and often when reached by bore-holes, yield Artesian springs rising to the surface, though they can rarely be depended on for a large and permanent supply of water; (3) at the natural or artificial intersection of a permeable resting on an impermeable bed, the former not requiring to be fully saturated to yield springs:—this occurs commonly at sea-cliffs and cuttings, when the

slope of the beds is towards the cliff or cutting; (4) at open faults, where the natural descent of a wet bed of loose texture is stopped, and the water rises nearly to its former level, often in this way producing natural Artesian springs; (5) at anticlinal axes, owing to pressure from below, probably connected with chemical action:—this and the former case frequently resulting in mineral springs, sometimes of high temperature. Besides these, which may be regarded as natural causes of springs, artificial supplies of water may often be obtained by penetrating through surface deposits to wet, permeable beds, occurring between impermeable beds, and receiving their supplies from a higher level than that reached by the boring; or by piercing natural reservoirs or open channels in impermeable rocks, supplied also from a higher level, and by channels full of water and producing pressure.

1049. Artesian wells are so called from the French province of Artois, where, so far back as at the beginning of the twelfth century, it was the custom to obtain springs of water artificially by piercing the soil to a certain depth in places where no indication of springs existed at the surface. When, therefore, in other districts water is obtained by boring, and the water thus reached rises to the surface, or attains a considerable height in the well, the term Artesian is applied, and serves to distinguish these springs from others which flow on a hill-side, or at faults, or in which there is no tendency to rise above the level of the water-containing bed, or natural underground reservoir. Dr. Buckland has indeed proposed to limit the term to those wells in which the water rises above the surface; but the proximity to the surface to which the water will rise is so entirely dependent on irregularities of surface that such a limitation could only induce confusion, and we greatly prefer the more general and recognised definition.

1050. Of the different kinds of rocks met with in nature, sands and gravels may be considered the most open, but both require careful examination if we would discover their true condition. Thus, many sand rocks, although themselves loose and containing much water with which they would readily part, have undergone a partial consolidation, or are traversed by a multitude of crevices, and sometimes by systems of faults parallel to each other, filled up with clay, quartz, or oxide of iron, and crossed by others at right angles to them. The whole mass of rock is thus divided into compartments or cells, which have little communication with each other, and one such compartment being drained by pumping, others at a distance are not necessarily affected. When part of a rock of this kind is covered with gravel little difference might be anticipated; but if the surface-gravel covers up and conceals boulder clay of a stiff and tenacious character — and this is by no means uncommon in various parts of England—the compartments above alluded to will be very differently filled with water in various parts of the same district.

Loose sand rock alternating with bands of marl and not intersected by impermeable bands, such as forms the great mass of the New red sandstone series in the middle and south of England,

usually allows water to percolate freely to its base, the marl beds only forming local interruptions, and retaining the water at the surface only so long as it is running towards some natural vent. Harder sands and sandstones, such as the millstone grit, form an almost impassable barrier for water, and conduct it to some other more permeable rock.

1051. Clays when of considerable thickness and extent do not allow water to pass downwards into the earth, and often by their level and easily-smoothed surface retain large pools and sheets of water to the great injury of the soil. When there is a natural fall to the sea, however small, there is always a possibility of greatly improving the condition of such land by drainage, while springs of water are neither required, nor if required would they be easily found without sinking. It may easily happen—and the geological structure of the district would show whether this is likely or not—that the clay covers up permeable and very wet beds, which would rise to the surface in Artesian wells.

1052. Calcareous or lime rocks differ very much in their containing power with reference to water, and much doubt has long existed as to the true state of such rocks in particular cases. They may be divided into two groups—the one partaking more or less of a spongy nature, and the other hard and semi-crystalline. The Oolites offer a kind of intermediate condition. The first of these groups is illustrated by chalk, of which the soft upper beds are exceedingly porous and absorbent of water, but through which, after all, water percolates but slowly. The lower beds of chalk, though not so soft, are almost always, when penetrated by sinkings, found to be exceedingly wet, and a large part of the water yielded freely, though the replacement of very large quantities rapidly removed seems to take place but slowly. In addition to the ordinary sources of water in the mass of the rock, there is no doubt of the existence of numerous fissures and crevices, and frequent large cavities, in chalk and all other lime rocks, and these are often filled with water at a very considerable pressure.

1053. As a rock which has for various reasons attracted great attention, and been very differently described, it may be worth while to consider in some detail the chalk of England, which presents a wide range and is pretty uniformly exhibited under the same mineral type. Chalk has a specific gravity from 2·40 to 2·55, or thereabouts; and by the assistance of his friend and colleague Dr. Miller, Professor of Chemistry in King's College, the author is able to give a correct idea of the condition of the rock in respect of absorbent power.

The experiments mentioned below were made in the King's College laboratory on three specimens of chalk, one (No. 1) from the upper chalk near Box Hill, another (No. 2) from the middle bed near Tring, and the third (No. 3) from the lower beds, probably

chalk-marl, near the bottom of the chalk towards the extremity of Tring Cutting. The chalk being cut into slabs weighing about a quarter of a pound each, were weighed in their ordinary state after being for some months exposed to the air—then when absolutely dry—and lastly when saturated by immersion into water *in vacuo*. The weight when absolutely dry being regarded in each case as 1000, we have

	No. 1.	No. 2.	No. 3.
Weight in ordinary state	1002·73	1002·30	1010·15
Weight when saturated	1186·57	1160·00	1161·02
Pounds of water in a cube foot of wet chalk	24·987	20·628	21·349
Bulk of water in chalk, a cube foot being unity ..	·4	·33	·34

From this it is evident that at least one-third of the bulk of fully saturated chalk consists of water, so that at a rough estimate there are about 2 gallons of water in each cube foot of wet chalk. It also results that some kinds of chalk (No. 3) contain one per cent. of water (by weight) even when apparently dry, while the upper chalk scarcely contains more than from 2 to 3 parts in 1000 under those circumstances.

1054. The following table showing the weight and volume of water contained in several other well-known rocks when saturated, will be found useful. The saturation is not under an exhausted receiver.*

ABSORBENT POWER OF VARIOUS ROCKS.

Name of stone.	Locality.	Quality of stone.	Weight per cube foot. lbs. oz.	Grains of water absorbed in each cubic inch.	Bulk of water absorbed (2 in. cubes =1).
Craigleith	Edinburgh	Sandstone	145 14	20·4	0·080
Darley Dale ..	Derbyshire	Do.	148 3	18·5	0·072
Mansfield red ..	Nottinghamshire ..	Do.	148 10	26·3	0·104
Do. white	Do.	Do.	149 9	23·5	0·092
Ancaster	Lincolnshire	Oolitic limestone	139 4	42·0	0·166
Barnack	Northamptonshire	Do.	136 12	36·0	0·141
Bath (Box) ...	Wiltshire	Do.	123	42·8	0·169
Ketton	Rutlandshire	Do.	128 5	38·2	0·151
Portland......	Dorsetshire......	Do.	135 8	34·4	0·135
Bolsover	Derbyshire	Magnesian limest.	151 11	20·1	0·079
Brodsworth ...	Yorkshire	Do.	133 10	54·6	0·215
Park Nook ...	Do.	Do.	137 3	56·0	0·221
Chilmark	Wiltshire.	Siliceous limestone	153 7	7·2	0·068

1055. With regard to the fact that in limestones, and such like rocks, there do exist great natural caverns, and that even in clayey beds there are alternating bands of sand and gravel capable of receiving a considerable quantity of water, communicating with the surface and sometimes passing down to immense depths, there can be no

* Report of Commissioners on building stones for the Houses of Parliament.

doubt whatever; and it is equally certain that in some of them, at any rate, the sheets of water are of very considerable extent. This is known not only by the examination of such rocks of the kind as are exposed at the surface, and by the appearances they there present, but also from the occasional cavities discovered in boring for Artesian wells, and also in sinking deep shafts in mining districts.

1056. As being perhaps one of the most interesting of these, and proving that springs obtained from great depths are sometimes dependent on atmospheric supplies and obtained by means of the peculiar geological structure of the country, we may mention the case of a fountain at Nismes, in the south of France, the supply from which, even in times of great drought, amounts to 145 gallons of water per minute; but it is found that, when it rains heavily at a distance of about six or seven miles from the fountain, in a north-westerly direction, an increase takes place suddenly in the supply, so that it then sometimes pours forth as much as 1000 gallons per minute, the temperature of the water supplied undergoing no change. It is clear in this case that the spring must be fed from a distance, and by means of long channels, which allow the water to flow rapidly through them. The rapidity of communication also is so great, that these channels must in all probability be open.

1057. As other instances may be quoted, 1st., the rock of Torghal, in Norway, which is pierced from end to end (more than 3,000 feet) by a rectilineal opening 150 feet high. 2nd. The celebrated cavern of Adelsberg, in Carniola, which receives the waters of a river, contains a large lake, and has been traced for a distance of at least six miles, but is probably much more extensive. 3rd. The fountain of Vaucluse, which issues from subterraneous rocks, and pours forth a volume of upwards of 13,000 cubic feet per minute, even under ordinary circumstances, and this increases sometimes to 40,000 cubic feet. There is also proof that many of these caverns and subterraneous rivers communicate with the surface, for fish, and even seeds, are occasionally conveyed into them with the water.

1058. During some sinkings near Dieppe as many as seven great sheets of water have been tapped; and under the city of Tours there appears to be distinct evidence of the existence of a subterraneous river, for on one occasion the fountain in the Place de la Cathédrale (sunk to 335 feet), brought up portions of vegetable matter, among which were branches of thorns an inch or two long, the stems, roots, and seeds of marsh-plants, and different kinds of grain; and fresh-water and even land-shells were also found mingled with these remains, which from their condition appeared to have been several months under water.

1059. The actual source of fresh supplies of water to all rocks must ultimately be the atmosphere, and the quantity received in each year in a given district is thus calculable within certain limits, if we know the area of drainage, the nature of the rock, its dip, strike, and faults, and its absorbent powers, the depth of rock of the kind observed, and the nature of the underlying bed. The overlying superficial deposits must also be understood, as the presence of clay in these will manifestly affect the result to a very considerable extent. Lastly, we must know the mean annual rain-fall in the district, the

extent to which evaporation goes on, and the seasons of the year at which rain chiefly falls.

The mean annual rain-fall in the vicinity of London and in the East of England is generally estimated at 26 inches. On the west coast, and especially near hilly or mountain districts, it is much greater, and in some particular spots is more than five times that amount. The quantity of water absorbed will depend so much on the nature of the rock, the season, and the condition of the land, if cultivated, that any calculation must be exceedingly conjectural. It is not unlikely that as much as 12 inches, the usual estimate, may be within the mark in the case of chalk, which, when very dry, absorbs with extreme rapidity. In calculations made afterwards only half that quantity has been assumed, and this there can hardly be a doubt must be greatly within the true amount.

1060. A familiar but very important example of the quantity of water present in a rock may be here given from the beds immediately round London. These are well known to consist of clays reposing, first, on beds of shingle, sand, and other material of loose texture, and then on chalk, which extends to some distance both north and south. Both clays and chalk are partly covered also with gravel, some of which is open, and allows water to run freely through it, while some contains much clay which would hold water to any extent. The clay, called "London clay" and described in a former chapter, is tough, and of course impermeable, and bore-holes put down, or shafts sunk to any considerable depth in the bed, or to its base, generally, but not always, yield much water, which rises in the well sometimes above the surface, often to the surface, and most frequently to some height without reaching the surface. When water is lifted by subterranean pressure above the level of a water-containing bed below the surface, the wells are, as we have seen, Artesian, and must in all cases involve the drainage of a district at some distance from the overlying surface. The very fact of the welling or springing up of water when a particular bed or reservoir is reached, seems to require, as a matter of absolute necessity, that there should be a bed lying above that which yields the water, and which is in some measure impermeable, although no doubt a relative impermeability is sufficient when the overlying beds are also wet.

1061. The cause of the water-supply obtained at the base of the London clay, is the presence there of sands and shingles cropping out at the rim of the basin, generally at higher levels than the clay itself. These beds conduct water pretty freely, and a large quantity is retained either on the surface of the chalk or on some bands of plastic clay occurring amongst the sandy and shingly beds. The cause of the very great irregularity of the supply from wells sunk into these lowest Tertiary deposits, seems to be partly the irregular nature of the lower beds, partly the very uneven surface of the chalk, and partly the fact that in some sinkings a reservoir is reached and in others only a portion of a wet bed is intercepted.

The actual supply of water between the chalk and the true London clay may be very roughly estimated as follows.—There are nearly 300 miles of outcrop of the plastic clay series, which may be considered to average about a mile in breadth, and of this one half may be permeable. The supply from 150 square miles of country, at six inches of rain absorbed per annum, would be about 12,000,000,000 of gallons

annually, and the actual quantity present, estimating the total area of the permeable beds of plastic clay beneath the London clay at 2,000 square miles, the mean thickness of the permeable beds at twenty feet, and the bulk of water at one-fourth that of the sands, will be about 1,500,000,000,000 of gallons. It would, however, require sinkings over the whole area to obtain any large proportion either of the contents or the annual supply even if continuous pumping were resorted to, and in any case there can be no doubt that the quantity rising above or near the surface from Artesian wells merely sunk through the clay would be in time much diminished.

1062. To return, however, to the case in point. The actual range of the chalk in England may be divided into two parts, the one extending northwards, between the gault and lower cretaceous beds in Kent and Surrey and the continuation of the anticlinal of the Weald to Devizes; and the other reaching southwards from that line. These two areas must be disconnected as far as drainage is concerned, for they have opposite dips, and we must consider the whole northern district by itself. Measuring from this line to the outcrop of the gault in Berkshire, Buckinghamshire, Bedfordshire, and Cambridgeshire, as far as the north coast of Norfolk, we have an area which may be estimated, very roughly, at about 8000 square miles, of which nearly one half is covered up by the beds of the London clay. 2000 square miles more are covered by newer Tertiary deposits, which may also be regarded as impermeable to water, so that there may possibly remain 2000 square miles of chalk surface exposed to the action of the rain. But we must once more make a division of this area, for we find, on examination, that one part dips towards the north and the rest towards the south-east, a large intermediate portion being very little inclined. The north downs of Kent and Surrey, and possibly a portion of the chalk near Marlborough, have the former inclination, and the rest of the range of the chalk hills the latter; so that the great triangular hollow or basin occupied by the London clay is a synclinal axis, receiving the drainage of the chalk hills on both sides of the valley. If, therefore, the chalk is found wet at moderate depths near the outcrop of the beds of London clay, which is generally the case, and if also the chalk really acts as a sponge, all sinkings into the chalk itself through the London clay ought to yield water at once, in considerable and nearly uniform quantity, which is decidedly contrary to experience. Either, therefore, the chalk is not freely percolated by water, or there is some local cause for the imperfect transmission of water under the London basin. It seems probable that very deep sinkings into the chalk under London will generally yield a large supply of water, although at various depths and in different quantities.

1063. But if we regard the chalk as a stratified deposit, presenting bands of somewhat different texture and different water-containing power, broken into innumerable crevices, traversed by numerous fissures and joints, and occasionally faulted, we shall probably obtain

a clue to the real cause of the irregularities of the water-supply in this rock. On reaching any one of the less permeable bands, or any considerable crevice at a depth from the surface, we may expect to find a large body of water, while when any large unbroken mass, whether more or less porous, is pierced, there is either no large supply at all, or a supply very easily exhausted.

1064. Limiting the problem and its conditions yet further, we may regard the chalk on the southern edge of the London basin as having generally a northern dip, and yielding with some freedom a number of springs, coming out along or near the northern exposure of the beds on the right bank of the Thames. The whole exposed surface of chalk between the sea-coast and London may be divided into four portions. First, between the Downs and the river Stour; second, between the Stour and the Medway; 3d, between the Medway and the Darent; and 4th, between the Darent and the natural opening between Greenwich and Godstone, nearly traversed by the line of the South-Eastern Railway. Between the Stour and the Darent, a district throughout which there is chalk at no great depth coming out often on the banks of the river, there are about 180 square miles of chalk exposed, and an area about as great is covered up with the London clay between the chalk and the right bank of the Thames. It may, therefore, very safely be asserted that there are in this area about 350 square miles of wet beds, either cropping out near the river, or capable of being readily tapped, while there are, also, not less than 150 square miles in addition between the Darent and the South-Eastern Railway. Now calculating from the best known data, this area of 500 square miles will contain in each yard thick of a fully saturated bed, as much as 14,000,000,000 cube feet of water, or in each yard thick under ordinary conditions of full absorption, about 12,000,000,000 of cube feet: in other words, there are about 1,800,000,000 gallons of water in every yard thick of wet chalk for each mile of outcrop; and if natural springs be taken up or tapped at intervals, a certain proportion of this might no doubt be obtained for general purposes. We have taken one yard of thickness as a convenient quantity, readily modified to any other thickness.

It might be supposed that a part at least of the water falling on the impermeable beds, whether London clay or belonging to more modern deposits, would add to the supply by draining from its surface. This may be the case to a small extent, especially where small streams come over such deposits, and are lost after passing over some distance of chalk; but it is not likely seriously to affect the question, since there must be a good deal of evaporation from such surfaces in warm weather when much rain falls, and the superficial coating of soil and gravel almost always allows the water to enter partially, and prevents immediate drainage to a lower level.

1065. There is, however, a great difference between the supply obtainable from springs on a line of outcrop, and that from deep sinkings within a comparatively small area. In the chalk especially,

this must be the case, for the percolation of the water through the mass of the rock, if in any sense complete, must be, and certainly is, very slow, a well of exhaustion—as a well constantly kept pumped down is called,—affecting the immediate surface to a very marked extent, but not producing much observable difference at a distance, even when only a few hundred yards.

1066. At Sheerness, water is obtained in the lower part of the London clay at about 300 feet, and then rises above the level of the ground. At Fulham, the London clay does not appear to contain a supply, but sinkings of about seventy feet in the underlying chalk have been attended with success. At Hammersmith, sinkings to 360 feet, and at Chiswick, in the gardens of the Horticultural Society, at 330 feet, abundant supplies have been obtained; but in the Duke of Northumberland's grounds above Chiswick, no water was obtained at the junction of the London clay and the chalk, nor until the latter rock had been penetrated to a great depth. At 620 feet, however, a reservoir was tapped which delivered the water not only at the surface, but about four feet above it. Other notices of sinkings into the chalk are given hereafter.

1067. The whole quantity of water in the chalk of England must be enormously great, but is hardly calculable. At the very lowest conceivable estimate, considering the total area as 6000 square miles, the mean thickness only 300 feet, and only one-third of this fully saturated to the extent of one-fourth its volume, it would amount to twenty-five millions of millions of gallons; while the annual supply from rain to the extent of six inches of water absorbed per annum over an area of 2000 square miles, would amount to nearly 175,000,000,000, or more than $\frac{1}{150}$th part of the whole quantity of water contained. If the population of the chalk districts, including the whole area covered by London clay and gravel, be taken at 4,000,000 of individuals, and fifty gallons per day be allowed for each, a very large and sufficient quantity for all possible sanitary purposes, there will thus be needed only about 72,000,000,000 gallons per annum for this purpose, or not much more than a third of the estimated annual supply from rain, and only $\frac{1}{350}$th part of the quantity contained in the rock. It is unnecessary to state that only a part of this is directly available; but there must be a very large proportion that could be pumped out, although it may be a very different question as to how far this mode of obtaining water on a large scale is economical, or in other respects advisable.

In the above estimate the quantities throughout are reduced to the very lowest that can be imagined, to show that the supply of water must be much greater than any demand that can arise. In point of fact, the proportion of rain entering the rock is more likely to be 12 inches than 6; the mean thickness of chalk might fairly have been taken at 600 feet instead of 300; and the quantity of water contained, instead of being taken at one-twelfth, may have been considered one-sixth of the bulk. Estimated in this way, the quantity of water in the chalk would be 100,000,000,000,000 gallons, and the annual supply 350,000,000,000. In addition to the quantity of rain, a large supply of water must enter some parts of the chalk from mere absorption from the atmosphere.

1068. The quality of water is unquestionably affected by the rocks through which it passes: although in this respect it is not always

safe to conclude what the result will be without actual investigation. Thus water obtained from surface-deposits is almost sure to contain in solution some of those organic substances which in cultivated land must always abound, and which are always carried down to some little distance by the descending supply of rain; water from irony rocks, whether sand or otherwise, being generally chalybeate, and that from calcareous rocks holding carbonate and other salts of lime in solution. But when we examine the analyses of different rocks, as given in previous tables, there will be found also a number of other ingredients, as salts of soda, potash, magnesia, and other substances, and these will also be taken up, while the very action of water and the decompositions otherwise going on, produce sulphuric acid and thus again act upon the containing rock, or alter combinations already in solution in the water. Thus it results, that in wells, however the water is obtained, there will be a certain proportion of saline and other ingredients, although the actual quantity may be less in amount and different in character in the case of deep and shallow wells in the same locality.

1069. It appears from a paper by Professor Brande, in the Quarterly Journal of the Chemical Society, vol. ii. p. 345, that a well was sunk 426 feet deep, into 202 feet of chalk to supply the Mint. This well was completed 1st of January, 1847. The water rises to within 80 feet of the surface, and about 45,000 gallons per day are obtained; the level being then reduced by this amount of exhaustion to about 100 feet from the surface.

Before the water was obtained from the chalk it yielded 44 grains of dry saline matter in the gallon of water. Since the well was finished the quantity is only 37·8 grains:—SG at 55°=1000·70. The following table will show the contents of this and two other deep wells into chalk:—

	Trafalgar Square. 265 ft. of chalk.	Mint. 202 ft. of chalk.	Camden Town. 166 ft. of chalk.
Chloride of sodium	20·058	10·53	11·10
Carbonate of soda	18·049	8·63	17·60
Sulphate of soda	8·749	13·14	13·00
Sulphate of potash	13·671		
Carbonate of lime	3·255	3·50	
Carbonate of magnesia	2·254	1·50	
Phosphate of lime	0·034		
Phosphate of soda	0·291		
Phosphoric acid	....	Trace	
Silica	0·971	0·50	Trace
Organic matter	0·908	Trace	2·30
Iron	....	Trace	....
Total grains per imp. gallon..	68·240	37·80	44·00

1070. Mr. Brande thinks chalk water generally more pure than that obtained nearer the surface in wells in the London Basin, and he states that it contains a smaller proportion of solid ingredients. He gives a list, showing the solid contents of various waters from several localities and depths, of which the following is a selection,—

		Gr. per imp. gal.
Artesian well at Grenelle	1794 ft.	9·86
Thames at Teddington		17·40
„ Brentford		19·20
„ Westminster		24·40
„ Greenwich		27·90
New River		19·20
River Colne		21·30
River Lea		23·70

		Gr. per imp. gal.
Deep well, Royal Mint	426 ft.	37·80
„ Hampstead waterworks	450 ft.	40·
„ Apothecaries Hall		45·
„ Goding's brewery, Lambeth		50·
„ Combe and Delafield's brewery		56·80
„ Berkeley Square		60·
„ Notting Hill		60·
„ Trafalgar Square	510 ft.	68·24
„ Tilbury Fort		75·

A few shallow wells contain 105 to 115 grains—among these are some from near churchyards.

1071. Very important questions sometimes arise as to the true extent of surface area which supplies the river drainage in certain districts, and although this subject has already been considered on a large scale, as to the area of river basins, it needs further elucidation. Certain rocks, chiefly sandstones and grits, are at the same time hard and unfractured by crevices, and, therefore, allow water to flow over them without either loss by absorption or injury by the admixture of impurities. These rocks are eminently impermeable and favorable for holding water in reservoirs, while others equally impermeable —as clays—abound in mineral substances readily taken up. It should also be remembered that a certain amount of exposure to air is useful and almost essential to give water its valuable properties for household purposes, the oxygen obtained by absorption in that way being desirable. Thus river water is beyond doubt the best adapted for all household and sanitary purposes, and next to river water must be ranked pure spring water, which has been long exposed to air, and kept in motion for a certain time while flowing in a confined channel or thrown up in fountains. A comparatively small area may sometimes supply a very large quantity of water when full advantage is taken of local peculiarities, although under other circumstances many times that area would not yield more than a few small streams.

1072. It is very necessary to pay attention in well-sinking to the beds passed through; as these, though by no means the same in the same district, yet resemble each other so far that a knowledge of the facts will be always useful. We append as a fit conclusion to this part of the subject a copy of the sinkings in two Artesian wells—one through the London clay into the chalk in the middle of London, and

the other through the whole series of Tertiary beds and the chalk in Paris. Both may safely be called successful, and to nearly the same extent; the quantity obtained amounting in each to between 300 and 400 gallons per minute, although in the one case at Paris the water rises to and is delivered at the surface, whereas in London it is pumped from a considerable depth. The last 500 feet in the Paris boring is only 6 inches in diameter diminishing from about 1 foot. The wells in Trafalgar Square commenced the one at 6 feet, and the other at 4 feet 6 inches, were diminished at 170 feet down, and at 300 feet were only continued by small bores.

Sinkings in the Artesian Wells at Trafalgar Square and Grenelle.

TRAFALGAR SQUARE, LONDON.

		Feet.
Made ground		15
Gravel, shifting gravel and sand		10
LOWER TERTIARY DEPOSITS.		
London clay	145	220
Thin layer of shells		
Plastic clay	30	
Gravel, &c.	10	
Green sand	35	
CHALK		265
Total feet		510

GRENELLE, PARIS.

	Feet.
Gravel and sand	13
LOWER TERTIARY DEPOSITS	
Cockle shells Quartzoze sand with fine particles of iron pyrites. Fine sand. Argillaceous sand. Mottled clay. Sand and clay with calcareous nodules.	167
CHALK SERIES.	
White chalk with flints. White chalk with beds of carbonate of magnesia and small flints. Grey chalk with small particles of silex. Grey chalk compact and without silex. Green chalk and green particles of silicate of iron. Blue argillaceous chalk. Blue argillaceous and sandy chalk with particles of mica and veins of green chalk.	1454
UPPER GREENSAND SERIES.	
Clay with iron pyrites, nodules of phosphate of lime and fossil debris (*gault*). Green sand. Clay and greenish sand with quartz grains. Argillaceous sand. Green and white sand. WATER.	160
Total feet	1794

4. *On Earthy Minerals used in Construction.*

1073. The department of Practical Geology on which we are now entering has already been the subject of some notice in previous chapters where the composition and structure of various kinds of rocks have been described. Thus the different kinds of clay used in pottery and other similar purposes, and in brick-making—the slates—the various limestones, magnesian limestones, and sandstones so common as building materials, and the marbles, porphyries and other ornamental stones;—all belong to this, and have each in turn been described in some detail.

1074. Clays vary much in value and are required for very different purposes, so that we have brick-clays, fire-clays, pipe-clay, porcelain-clay and Fuller's-earth, and amongst metamorphic rocks various kinds of slate. Analyses of these will be found in TABLE IV., p. 260, and their properties and uses need not be here enlarged on.

1075. Limestones have also been described, and the circumstances of their mineral composition fully explained. The kind most usually employed in important constructions in the South of England is Portland, and in the midland and eastern counties the varieties from Northamptonshire; while the use of the magnesian limestone has been chiefly limited to the north of Derbyshire and Nottinghamshire and the south of Yorkshire, where such beds offer the cheapest and best material. A method adopted by M. Brard to determine the relative value of various stones as building material is especially adapted to the case of Oolites and other calcareous rocks in the middle of England. It cannot be applied with any certainty to other rocks.

1076. The object of this process is to discover in a short time the relative resistance offered by different kinds of stone to the action of damp and frost, and therefore to determine the durability of stones with reference to exposure. Its accuracy was determined by a number of experiments made in different parts of France and Switzerland, and by different persons, and reports to this effect were published in the "Annales de Chimie" for 1828, vol. xxxviii.

The following is an abstract of the method recommended to be employed:—

1. Several specimens should be selected from the questionable parts of a block of stone to be tried, taking, for instance, those which present differences of colour, grain, or general appearance.

2. These fragments should be cut into two-inch cubes, with sharp edges, and each marked carefully, so that the part of the block from which they came may be referred to.

3. There must next be prepared a saturated solution of Glauber's salts (sulphate of soda), the solution being made with cold water, and a quantity of the salt left for an hour or two at the bottom, after as much has been taken up as the water will at first absorb. (It will be found that a quart of water absorbs more than a pound of this salt at ordinary temperatures.) The saturated solution is then to be boiled, and the cubes prepared are to be plunged into the vessel in which the solution is boiling violently, care being taken that each one of the cubes is completely submerged. The boiling is then to be kept up, and the stones retained in the boiling liquid for half-an-hour exactly. If a longer period elapse, the effects produced exceed those of ordinary atmospheric action and frost.

4. When the boiling is completed, each specimen is to be withdrawn successively, and suspended from a string, taking care that it touches nothing else, and is completely isolated. Beneath each there is also to be placed a vessel full of a quantity of the solution in which it has been boiled, care being taken that it contains no fragments of the stone detached during the boiling.

5. If the weather is not too wet or too cold, it will be found that the surface of the stones, four and twenty hours after they have been suspended are covered with small white, acicular crystals of salt. When these appear, the cubes are to be plunged into the vessel below them, to get rid of the efflorescences ; and this is to be done repeatedly, as often as crystals of salts are thrown out during the experiment.

6. If the stone resist the decomposing action of damp and frost, the salt does not force out any portions of the stone with it, and one finds neither grains, nor laminæ, nor other fragments of the stone in the vessel. If, on the other hand, the stone yield to this action, small fragments will be perceived to separate themselves, detached even from the first appearance of the salt, and the cube will soon lose its angles and sharp edges. The portions thus detached are preserved at the bottom of the vessel over which the cube is suspended, and their weight may be determined at the completion of the experiment.

7. The period of duration of the experiment, as recommended by M. Brard, should be four days, and at the end of that time the particles detached should be carefully weighed. The result is an index of the amount of disintegration suffered by the stone, and may be compared with similar results from other stones.

1077. With respect to the decomposition of stones employed for building purposes, it is greatly influenced, as well by the chemical and mechanical composition of the stone itself and by the nature of the aggregation of its component parts, as by the circumstances of exposure. The Oolitic limestones will thus suffer unequal decomposition, unless the little egg-shaped particles, and the cement with which they are united, be equally coherent, and of the same chemical composition. The shelly limestones, being chiefly formed of fragments of shells, which are usually crystalline and cemented by a calcareous paste, are also unequal in their rate of decomposition, because the crystalline parts offer the greatest resistance to the decomposing effects of the atmosphere. These shelly limestones have also, generally, a coarse laminated structure, parallel to the plane of stratification, and, like sandstones formed in the same way, they decompose rapidly when used as flags, where their plane surfaces are exposed ; but if their edges only are laid bare, they will last for a very long and almost indefinite period.

1078. Sandstones, from the mode of their formation, are very frequently laminated, and more especially when micaceous ; the plates of mica being generally deposited in planes parallel to the beds. Hence, if such sandstone, or shelly laminated limestone, be placed in buildings with the planes of lamination in a vertical position, it will decompose in flakes, more or less rapidly, according to the thickness of the laminæ ; whereas, if placed so that the planes of lamination are horizontal,—that is, as in its natural bed, the edges only being exposed, the amount of decomposition will be comparatively immaterial. The sandstones being composed of quartzose or siliceous

grains, comparatively indestructible, they are more or less durable according to the nature of the cementing substance; while, on the other hand, the limestones and magnesian limestones are durable in proportion rather to the extent in which they are crystalline; those which partake least of the crystalline character, suffering most from exposure to atmospheric influences.

1079. The chemical action of the atmosphere produces a change in the entire matter of the limestones, and in the cementing substance of the sandstones, according to the amount of surface exposed. The mechanical action due to atmospheric causes, occasions either a removal or a disruption of the exposed particles; the former by means of powerful winds and driving rains, and the latter by the congelation of water forced into, or absorbed by, the external portions of the stone. These effects are reciprocal, chemical action rendering the stone liable to be more easily affected by mechanical action, which latter, by constantly presenting new surfaces, accelerates the disintegrating effects of the former.

1080. On the whole, it would appear that, where there are no local reasons to the contrary, preference should be given to limestones over sandstones for most public buildings intended to be handed down to future ages; and this on account of their more general uniformity of tint, their comparatively homogeneous structure, and the facility and economy of their conversion to building purposes. Amongst the limestones, also, those which are most crystalline are to be preferred; and some of the magnesian limestones seem to offer the greatest advantages of durability, uniformity of structure, beauty of appearance, and facility of conversion; but it should be clearly understood, that many other limestones, and many sandstones, also form admirable building stones; and these are so distributed through the country, that there is now no excuse for those architects and engineers who neglect to examine carefully into the relative durability and excellence of the stone employed in any edifice about to be constructed.

1081. It might also be shown, that if more attention had been paid to the qualities of stone, the frequent decay observable in many buildings, erected even within a few years, might have been avoided at comparatively small cost, and we should find fewer of our public edifices losing all traces of the finer work of their original structure. So long, however, as the opinion and judgment of the mason is allowed to decide on the stone to be used, so long will this result take place, for "the mason almost always judges by the freedom with which a stone works,—no doubt an important element in the cost of a building, but certainly one which should not be permitted to weigh heavier in the scale than durability."*

* De la Beche's Report, p. 486.

CHAPTER XIX.

ON MINING OPERATIONS AND THEIR REFERENCE TO GEOLOGICAL STRUCTURE.

1082. By mining, we understand all those operations by which mineral substances are obtained from beneath the earth's surface. It is chiefly in this way, by position, that mines are distinguished from quarries or open workings, and when any valuable mineral appears at the surface, forming the outcrop of a bed or vein, it is usually followed either by vertical shafts or horizontal galleries entered from a hill-side, so that all important workings must have reference to materials out of the immediate range of observation—whose position, probable condition, and extension, must be calculated from a general or local knowledge of strictly geological phenomena. An acquaintance with those facts of Geology recapitulated at the beginning of the last chapter, is, therefore, of most essential and vital importance, as without it all mining operations must be mere speculations of the wildest kind. All practical miners are, indeed, of necessity geologists to some extent, but though acquainted with some facts, they are often apt to think slightly of general principles, without which practical knowledge is mere empiricism.

1083. Mining operations are of two very distinct kinds: the methods employed having reference to the way in which the required mineral exists in the earth. Thus coal, salt, many ores of iron, and some of other metals, appear in regular layers, interstratified with and forming part of, the series of deposits which together make up the earth's crust at particular spots, while the usual ores of copper, lead, &c., occur in crevices formed in rocks after they have been deposited, and often since their subsequent metamorphosis. The attempt to obtain a portion or the whole of a deposited bed out of the midst of a number with which it has always hitherto been in contact, will be at once seen to involve difficulties altogether distinct from those incurred in clearing out the contents of a crevice or fissure, the walls of which ceased to be in contact before the material to be extracted was placed in its existing position.

In the present chapter we shall endeavour to place before the student the scientific principles of mining, both with respect to stratified minerals and those contained in lodes or veins traversing various rocks. All mere working details will be omitted, and all statistical facts, however important, must also be neglected as incompatible with the object in view. The principal substances obtained by mining may be described as coal, clay, ironstone, and salt, regularly

bedded, and various metalliferous ores in mineral veins: each of these in turn will require some notice.

1. *Mining for Coal.*

1084. The principal localities in which coal is found, and the circumstances of the deposit in each case, have been already mentioned, and the nature of the various kinds of coal and their uses have also been the subject of description.

There are two exceedingly important matters to be considered and understood before proceeding to describe the method of working in coal-mines, and these matters themselves are both eminently practical, both strictly dependent on that class of phenomena studied by the Geologist, and both, therefore, proper to be mentioned in this place, as connected with the Geology of practical mining. One of these is the frequent repetition or loss of the coal strata by faults and dislocations, and the other is the fact that those beds containing valuable fuel capable of being extracted and employed for economical purposes, are very rarely found except in one formation, and are even confined, for the most part, to a certain part of that formation, so far as practical mining is concerned; this being the case, not only in our own country, but wherever extensive deposits of coal have hitherto been found in Europe.

1085. The latter fact is one, the knowledge of which is obtained by experience only, and as to a certain extent it partakes of the indeterminate nature of all negative propositions, it may be considered as not yet fully proved. But the evidence, if not complete, is at least exceedingly strong; and the degree of probability that coal, as a valuable mineral, is confined to the upper part of the Palæozoic series of deposits, is so great, as to be a safe guide in all the speculations of prudent men. It is not that other groups of strata have always been formed at a distance from land richly clothed with vegetation; for, on the contrary, some (as the Wealden formations) are entirely of fresh-water origin, while parts of the carboniferous system seem almost exclusively marine; and others (as the beds of the Lower oolites) are associated with sandstone and shales loaded with vegetable remains. Other accumulations of ancient vegetable matter are found elsewhere, and indications appear in several of them of sandstones and shales, very similar to those associated with the coal; but the coal itself is always absent, or worthless, and a search for it in any bed of the Secondary or Tertiary period, seems sure to result in disappointment and failure. The Geologist can only lay this fact before the practical miner as the result of observation, but it is of great importance, and it is a case in which a sufficient acquaintance with Geology may be the means of saving the expenditure of

large sums of money, under circumstances where there was not from the first any reasonable prospect of success.

Numberless instances might be quoted of vain attempts that have been made to obtain coal in other rocks than those of the Newer Palæozoic period in Europe, and each experiment in succession has only served to strengthen the conviction that must exist in the mind of every observant Geologist, that few exceptions are likely to occur to the general rule in this matter. We have already given an account of one remarkable and interesting exception in America.

1086. The other fact to be considered by the practical miner, is that of the singularly frequent disturbances that have affected the beds of coal and the strata associated with them, and the remarkable complication of the *faults* that characterise many coal-fields. It must not be supposed that the effect of these disturbances is either uniformly advantageous, or always disadvantageous to the immediate interests of the miner; but there cannot be the slightest doubt that we are indebted to such disturbances for frequent repetitions of the same bed of coal at the surface, when without them it would be so far covered up by newer deposits as to be utterly unattainable. If occasionally the miner, in prosecuting his labours, or the mine-owner in following what he considers a valuable seam of coal, is suddenly stopped by coming in contact with a fault, and finds the coal shifted several yards above or below, or even completely lost, he must not forget that it is perhaps owing to these very shifts that the outcrop has taken place at all in his neighbourhood, and that the coal is workable in the district in which he is interested.

1087. But there is another important advantage derived from the existence of these numerous faults in coal strata, namely, that they intersect large fields of coal in all directions, and by the clayey contents which fill up the cracks accompanying faults, become coffer-dams, which prevent the body of water accumulated in one part of the field from flowing into any opening which might be made in it from another. This separation of the coal-field into small areas, is also important in case of fire, for in this way the combustion is prevented from spreading widely, and destroying, as it would otherwise do, the whole of the seam ignited.

1088. An instance of the advantage resulting from the presence of a great line of fault, occurred in the year 1825, at Gosforth, near Newcastle, where a shaft was dug on the wet side of the great ninety-fathom dyke, which there intercepts the coal-field. The workings were immediately inundated with water, and it was found necessary to abandon them. Another shaft, however, was sunk on the other side of the dyke, only a few yards from the former, and in this they descended nearly two hundred fathoms without any impediment from the water.*

1089. The chance of fire is not so hypothetical an accident as might, perhaps, be thought. Many instances are on record of fires having occurred, sometimes spon-

* Buckland's Bridgewater Treatise, vol. i. p. 544, *note.*

taneously, from the decomposition of iron pyrites in contact with moisture, sometimes from lightning, and sometimes wilfully, in consequence of quarrels between the workmen and the coal-owners. When coal-beds have once been ignited they have been known to burn on slowly for many years, and within the last twenty years there has been more than one instance of extensive subterraneous fires, which have destroyed many acres of coal.

1090. The stratified condition of the coal, and the high probability of discovering the seam or bed in every part of a district similarly circumstanced, would render the working for coal almost a mechanical labour, not requiring any special directions or any previous knowledge, were it not for the extreme abundance of faults, and the great influence they have upon the productiveness of a coal-field. But such previous knowledge, united with great experience, is exceedingly necessary, and requires to be founded on a familiar acquaintance with Geological phenomena.

1091. One of the most simple, though not the least important applications of Geological knowledge in mining, may be exemplified by considering the case of a coal-seam cropping out in a valley, since there are no less than three very distinct cases that may occur, in each of which the method to be adopted in working the coal must be contrived with reference to the Geological position of the bed, and not only to the fact of the coal cropping out. The first of these is when the dip of the beds is less than the angle at which the valley slopes, both being in the same direction, in which case a shaft sunk anywhere on the rise of the hill will reach the coal, the seam of which may be worked safely and with little difficulty, the newer beds being always the highest in position. Elsewhere, however, where the dip of the bed is greater than the slope of the valley, and the direction is still the same, no useful result would be attained by sinking on the rise, above the spot where the coal has once been seen, the older beds coming out on the rise of the hill. Both in this case and the former the outcrop of the coal may occur at about the same height on the rise of the hill, the alteration of the dip of the strata being the only point of difference apparent.

1092. The third case in which it is important to understand the Geological position of the coal strata occurs when the slope of the valley is in a different and nearly contrary direction to the dip of the beds. In this case the newest and not the oldest beds will necessarily appear the highest in position on the hill-side, and the coal may safely be looked for at a certain calculable distance below the surface.

1093. Having offered these preliminary observations, as to the circumstances of the occurrence of coal, let us next proceed to consider in what way, and under what conditions, the coal can be most conveniently extracted from the bowels of the earth ; and as these conditions depend partly upon the nature of the coal itself, partly on the thickness of the beds, and partly on their depth below the surface at

the place of working, and on the dip of the strata, it will be necessary to distinguish between the North of England coal-field, where the beds are of moderate thickness, exceedingly bituminous, and worked at great depths, and the carboniferous deposits in Yorkshire, Staffordshire, Warwickshire, and Wales, where they are either enormously thick, contain less gas, or can be conveniently obtained from depths much less considerable. The Newcastle coal being that chiefly made use of in England as a fuel, it will be convenient to bring it first under consideration.

1094. When by the various methods already described, or by previous knowledge of the district, the presence of coal is ascertained, the first operation to be undertaken before opening a coal-mine is usually that of *boring* to discover the most advantageous spot for sinking a shaft, and extracting the coal. This is often necessary, owing to the complexity of various systems of faults, and the impossibility of otherwise determining with certainty the prospects of sinking.

1095. The operation of *boring* is generally effected with a kind of chisel, which being attached to an iron rod by means of a screw, and worked by a little temporary machinery erected on the surface, makes its way by alternate chopping and scooping, the accumulation of rubbish being taken out from time to time by an auger, as the chisel becomes clogged. Successive lengths of rod are screwed on as the work advances, and the nature of the strata gone through is determined with considerable facility and certainty by examining the fragments brought up by the auger.

1096. When in this way, or from previous knowledge of the district, it is decided where a shaft shall be sunk, this important work has next to be commenced.

The shafts in the North of England are usually cylindrical or elliptical, and the smallest diameter is about ten feet. The smaller shafts are generally divided throughout into two compartments by an air-tight wall of separation (a *brattice*), but the larger ones, which have a diameter of as much as fifteen feet, are sometimes divided into three parts. One of the compartments is in this case made use of for drawing the coal to the surface, another for the drainage of the mine, and a third for ventilation, conveying to the surface the air that has passed through the workings.

1097. Under the most favourable circumstances, the sinking a shaft is a work of considerable time and expense, for it is necessary to line a great part of the interior with bricks to prevent the loose and incoherent strata from falling, or being washed in; but it rarely happens that any depth of shaft can be sunk without meeting with springs of water, which sometimes empty themselves into the workings to an extent which it would at first appear hopeless to contend

against. In such cases there is no safety to be obtained without lining, with a strong framework, that part of the shaft which passes through the loose permeable sands. This lining of the shaft is called *tubbing*, and many pits around Newcastle and elsewhere (where extreme durability is required, and no expense is spared to obtain this object) were formerly lined throughout with three-inch boards nailed to a circular wooden framework, called a *crib*, which was firmly attached to the sides of the pit at convenient distances. But this method, although it has been known to keep out a pressure of water equal to 100lbs. on the square inch, is not considered so safe as the *metal tubbing* now adopted in all difficult works. In some recent shafts as much as forty fathoms of a pit have been in this way completely lined with a strong cast-iron casing.

1098. The depth of the shaft must, of course, vary indefinitely; but in the Newcastle coal-field it is rarely less than twenty-five fathoms, or 150 feet. The most common depth is, however, much greater than this, pits being sometimes sunk to nearly 300 fathoms (1800 feet,) and an expense of upwards of 50,000*l.* being often incurred before the seam of coal has been reached which it is intended to work.

1099. The most remarkable and enterprising work of this kind on record, is a sinking at Monk-Wearmouth colliery, near Sunderland, commenced in 1826, through the capping of magnesian limestone. The lower beds of the magnesian limestone and the lower new red sandstone here overlap the coal-measures, and at the place of sinking their thickness was known to be upwards of 300 feet. At a depth of 330 feet accordingly the coal strata were reached, but, at the same time, a spring was tapped, which poured water into the workings at the rate of 3,000 gallons per minute. This fearful influx was kept under by a steam-engine of 200 horse power, and the work was made secure by a strong metal tubbing, and carried on successfully, though not without considerable difficulty.

On entering the coal-measures, however, a new and unexpected check was experienced. No calculation had been made for the extra thickness of the uppermost coal strata in those parts where the upper beds had been protected from denudation. This was found to require a much deeper sinking than had been expected; and the difficulties were increased when, at the depth of 1,000 feet, a fresh *feeder*, or spring of water, was tapped. Additional expense and great loss of time was thus caused; but the proprietors persevered, and continued the sinking to the depth of 1578 feet, where they were rewarded by reaching a seam of considerable thickness and value. This was supposed to represent the Bensham seam, and they therefore continued the work to the "Hutton," the most valuable of all. The expense of this pit, including the necessary preliminary operations, could not have been less than £100,000, and at least ten years elapsed before any result was obtained. Another more successful and less expensive sinking, also to an enormous depth and through a large quantity of water, has been recently concluded in the neighbourhood.

1100. It is usual in the deeper workings to have but few shafts, owing to the great expense of sinking; and it is the opinion of some of the most intelligent coal-viewers, that in this way, independent of all economical considerations, the deep workings are more conveniently and perfectly drained and ventilated, and that the general

work of the mine goes on better. It must be confessed that this opinion seems hardly reasonable when the great extent of the underground works to be thus ventilated is taken into consideration. In some mines upwards of 70 miles of passages, more than 100 fathoms below the surface of the earth, are only provided with one pit, not above 12 or 14 feet in diameter, for ventilation, drawing coals, pumping water, and every operation necessary between the surface and the works.

1101. It is rarely necessary in the coal-fields in the middle or west of England, or in Wales, to sink so deep for the coal, or undertake such costly works in order to obtain it; but the method of sinking is, of course, the same. In many places, however, it is found more convenient to sink a number of pits of smaller size than one large one, and in this way to avoid the extensive underground operations required in the north to effect the ventilation of such mines as have only a single shaft. The thickness of the coal in Staffordshire also renders it expedient to resort to methods of working on a principle somewhat different to that followed in the Newcastle coal-field, and these methods will require to be spoken of separately.

1102. The shaft being sunk, it is usual to drive two galleries, or levels, the one along a horizontal line on the strike of the coal-seam, and the other at right angles to this on the rise of the bed. The former is called the *drift*, or water-course, and has important reference to the drainage of the mine, and the latter is the *winning headway*, or main thoroughfare, through which the coal is conveyed to the shaft when extracted from the galleries afterwards cut. These two principal and preliminary cuttings are usually of considerable dimensions (from nine to twelve feet wide, and six feet high), admitting of the passage of loaded waggons and horses, and they are almost always provided with a tram or pair of rails. In the shallower mines, and where a second shaft is sunk, the new shaft opens at the extremity of the winning headway, and ventilation is at once established.

1103. The method of working must be decided on, not only with reference to the chance of explosion from certain gases afterwards to be described, but also after all possible information has been obtained, and calculation made as to the sustaining power of the roof and floor, the strata above and below which the coal is deposited. For it must always be remembered that although so long as the coal remains in its place there is no extraordinary pressure, every part being equally and proportionably sustained; yet so soon as the excavation has commenced, and empty spaces are left, the roof, if sufficiently coherent, causes the whole superincumbent weight to press on those portions of coal that may be left in the mine, which in that case act as pillars, and will inevitably be crushed if their dimensions and hardness are inadequate.

1104. If however the roof consist of hard sandstone and the floor of soft clay, the pressure downwards will tend to displace and force up the floor, and fill up the spaces left by removing part of the coal. If, on the other hand, the roof be soft, it will sink in, and if both roof and floor are moderately hard and tough, they may, after a time, meet each other mid-way. The surface sinking in, in consequence of this, the result called a *creep* is sometimes produced.

1105. Having acquired a knowledge of the nature of the coal itself, and of its floor and roof, it becomes a most important problem to be solved by the coal-viewer, how far he can safely proceed in taking away the coal, and in what way the maximum of produce can be obtained, with the minimum of danger and loss.

In the Newcastle coal-field, where the coal is full of gas, where the best seams are worked at very great depths below the surface, and where the strata associated with the coal are often soft and incoherent, it is usual to extract the coal by cutting a number of galleries parallel with each other, and intersected by others at right-angles—thus isolating between four such galleries a pillar of coal whose dimensions vary according to circumstances.

1106. In the description already given of the first operations of mining after the shaft is sunk, it has been mentioned that two levels, the *drift* and *winning headway*, are first completed, and after this other galleries are sometimes driven parallel to the winning headway. These galleries are of different dimensions, the larger ones, which are nine or ten feet wide, are called *boards*, and they are intersected by other galleries at right-angles to them whose dimensions are not quite so large, and which are called *narrows*. The pillars of coal left between these galleries, in Newcastle workings, must be from eight to nine yards thick, and until the close of the last century this method was the only one employed in deep workings, at least sixty per cent. of the coal being left in the mine.

1107. About fifty years ago, however, an attempt was made, for the first time, to remove a part of the pillars, and a method was devised by which fifty-four per cent. of the coal was obtained, and afterwards, this method succeeding, alternate rows of pillars were abstracted, and sometimes even half the intermediate ones. Lastly, Mr. Buddle invented the method called panel-work, by which nearly the whole of the coal may be obtained with safety.

This method consists in dividing the mine into districts or *panels*, separated from one another by walls of coal forty or fifty yards thick, and extracting the coal from each of such panels in succession, usually beginning with the one most distant from the shaft, and completely shutting off all communication with the rest of the mine as soon as any panel is worked out. Large pillars are at first left between the *boards* (which are four yards wide), and the

transverse galleries, (two yards wide), and the dimensions of the pillars are about twelve yards by twenty-four. As soon as the galleries are finished, and the work of removing the pillars commences, the roof is at first supported by stout props of Scotch fir, and when these are also taken away, the roof falls in; but the whole of the workings are kept under perfect control so far as ventilation is concerned, and any part can at very short notice be shut off from the current of air running through the whole mine, should such an arrangement be required.

The great advantage of Mr. Buddle's plan is, that while a large proportion of the whole bed of coal may be by its means extracted, the ventilation may be generally well preserved, and the risk of danger from accumulations of gas in old workings almost entirely avoided, because these old workings can be completely cut off from the mine as soon as they become in a dangerous state. The technical name for such workings is *pillar and stall*, or *board and pillar* working.

1108. Such being the method of working in mines where there is danger to be anticipated from the presence of inflammable or explosive gases, let us next shortly consider the nature of the different and simpler contrivances followed in those districts where the coal is not *fiery*, and where the associated beds are sufficiently hard and coherent to support themselves without fear of accident. These are called *long-wall* methods.

In the Yorkshire collieries there is something of the regularity observable in the mines of the Newcastle coal-field, but a greater proportion of the coal is worked out at first, and only a wall of coal is left. At least two pits or shafts are sunk, communicating with each other by a gallery called the *drift.* From the lower, or engine pit, a gallery is cut on the strike, and likewise another from the working pit, and these are called respectively the *water-gate* and the *horse-gate.* From the bottom of the working pit a main gallery is also driven on the rise of the coal, and this, which corresponds to the *winning headway* of the north of England, is here called the *main board-gate.* Other galleries, parallel to this, are also cut, and the coal is then worked from the intermediate pillars, leaving only a narrow wall, and allowing the roof to fall in after those temporary props are removed which supported it while the works were advancing.

1109. In Staffordshire again, where the seam of coal is of extreme thickness, and consists in fact of several beds united, the method is somewhat different, as there only a few irregular pillars are left; but there is still a wall of coal, although little regard is paid to those conditions which are justly considered as of the most vital importance in the mines of the Newcastle coal-field.

1110. The system of ventilation must, of course, be nearly the same in its general plan, whatever be the nature of the mine to which it is adapted; and therefore, in describing the most complicated and perfect arrangements of this kind, as carried on in the fiery seams of Newcastle and its neighbourhood, it will hardly be necessary to mention the smaller degree of the same care and attention paid in the less dangerous workings of other districts.

1111. Perhaps it is advisable, before proceeding to give an account of the ventilation of coal-mines, that the reader should be made acquainted with some technical terms that will be used in the description.

A *brattice* is a wall of separation. Brattices are of two kinds; either permanent, and separating a shaft into two or more divisions, in which case it is a strong parapet wall, sometimes as much as three feet thick; or temporary, and consisting only of a frame-work of three-inch deal, readily moved to any part of the underground workings. A piece of tarpauling will often be found serving the purpose of a temporary brattice.

Stoppings are walls made of brick, stone, or timber, and their object is to prevent the current of air from passing in a given direction. They are of considerable thickness, and in many cases consist of two stout brick walls, with many yards of rubbish between them.

Trap-doors are moveable substitutes for stoppings in the great thoroughfares of the workings. They are of several kinds; as *main-doors*, which are in sets of two or three, and always fixed in the strongest manner, and provided with boys to open them upon a signal, and take care that two of the same set are never open at the same time. *Man-doors* are of small size and communicate with the dangerous parts of a mine. *Sheth-doors* are those which purposely allow a certain degree of leakage; and *sham-doors* are a kind of trellis-work, only intended to check the current of air. *Swing-doors* are sometimes placed between two main doors.

The *air-course* is a general name for the air traversing workings where ventilation is going on. The fresh air descending into the mine is called the "*in-take*," and that which ascends, after having passed through the workings, is the "*return*."

A *crossing* is where a current of air crosses another current by means of an arch or small tunnel.

That part of a mine which is not included in the principal ventilation is called the *waste*.

1112. There are various modes of inducing the current of air by which the ventilation of mines is to be effected, but the most common is by rarefaction, a powerful furnace being placed at the bottom of the upcast pit. In some cases, indeed, it is not considered safe to resort to such an expedient for the whole of the air, in consequence of the quantity of gas poured out in the workings; and when, owing to this or any other reason, the furnace cannot be used, a hot cylinder has been substituted, or a current of air produced by throwing a column of water into the downcast shaft, or by pumping out the air by means of an air-pump or steam-jet from the upcast; but all these are partial and imperfect contrivances, and have many great disadvantages. The simple furnace has been proved by experience to be the most convenient method of producing the required current; and the portion of the air in a dangerous state may be conveyed into the upper part of the shaft by a contrivance called the *dumb furnace*.

1113. The effect of a large fire at the bottom either of a shaft, or

of a division of the shaft, is to add considerably to the rarefaction of the air as it passes out of the mine, and in this way to produce a rapid ascending column of hot air, whose place is immediately supplied by a rush of cold air from the surface, and this cold air, passing down the other pit, or another compartment of the shaft, and through the workings, is gradually warmed, until at last it reaches the furnace, and itself becomes the ascending column.

1114. The quantity of air passing into a mine varies very considerably, according to the magnitude of the workings, and the extent to which the down-current is distributed into different divisions or panels of the mine. As an example sufficient to give a clear idea of the principle of ventilation by splitting the air when underground, we may mention the case of the Hetton Colliery, one of the most extensive in the county of Durham, where experiments have lately been made which are recorded by Mr. N. Wood, in his evidence before the House of Lords. (See Report of Lords' Committee on Accidents in Coal Mines, 1849. Qu. 1816, *et seq.*) In this mine there are two seams now worked and one that has been formerly worked—two downcast shafts and one upcast, the former about twelve feet and the latter fourteen feet diameter; and three furnaces at the bottom of the upcast, each about nine feet wide and about four feet length of grate-bars. The depth of the upcast and one downcast, 150 fathoms, and of the other downcast, 176 fathoms.

The quantity of air introduced into the mine by the action of these furnaces was 168,850 cubic feet per minute, at a cost of about eight tons of coal per day. The rate of motion of the air was 1097 feet per minute.

This whole current is divided by splitting into sixteen currents of above 11,000 cubic feet per minute, having, on an average, a course of four miles and a quarter each. The distance is, however, irregular, the greatest length of course being nine miles and one-tenth. The effective velocity of the current in the actual workings of the mine is much checked by the multiplication of passages, the friction and other causes, and is thus reduced to from three to five feet per second; the smaller quantity being about the maximum rate attainable by the natural current in a small mine, where there will generally be from one to three feet. It has been estimated that the minimum quantity of fresh air required for the support of life in a mine is about fifteen or eighteen cubic feet per minute for each man employed.

1115. The current of air once obtained, is conducted through the passages of the mine by various contrivances, consisting of permanent stoppings of brick and rubbish, temporary doors and brattices, or partitions, and partial orifices or *scalings*. The arrangement of these is a matter of detail, varying in each mine and often in different parts of the mine: it depends also considerably on the mode of working adopted.

1116. Having said so much on the methods of ventilating coal-mines, we may conclude with a few words descriptive of the process actually followed by the miner in extracting the coal from its bed.

The working tools of the collier are few and simple, and consist chiefly of different forms of the *pick*, the most useful of which is a kind of mattock, with both ends of the head pointed. Besides this, chisels of various kinds, crowbars, hammers, and wedges, make up almost the whole list.

1117. The coal is in almost all cases readily detached by blasting, and is then easily broken up into cubical masses by taking advan-

tage of the natural joints or vertical cracks which traverse it, and which occur generally in sets parallel, and at right-angles to one another. Besides these the coal is also characterised by what are called *partings*, parallel to the stratification of the beds. The usual method of *getting* the coal is by blasting, and this is effected by piercing the lower part of the seam with a hole about an inch in diameter and a yard deep, into which the charge is inserted in cartridges, and the hole is afterwards plugged with coal-dust. When the blast has been fired, the coal is broken up by the hewer, who is usually paid according to the number of tubs, or corves, he is able to fill. These corves are conveyed on tram-roads through the mine, and ultimately lifted by machinery to the surface. The men employed in actually getting the coal, are called *hewers*,—the loaded waggons, or corves, are conveyed along the tram by lads called *putters*, as far as the principal galleries, or headways, and are there received into waggons called *rolleys*, several of which being attached together, they are drawn by a horse to the bottom of the shaft.

1118. Miners are generally lighted by candles, which they carry with them and attach to the wall of coal near their work, by a fragment of soft clay. Since however it happens that all bituminous coal contains a certain proportion of inflammable gas, usually carburetted hydrogen (or *fire-damp*), which is given off on the exposure of a fresh surface of the coal, and is often pent up in crevices and set free by ordinary workings, or by an accidental arrival at a fault,—and since, too, this gas is explosive in certain states of mixture with atmospheric air, a considerable risk is thus incurred which has too often resulted in accidents, amongst the most frightful that can be imagined. Attempts have been made at various times to remedy the evil by the introduction of lights which should not explode the gas; and of all contrivances of this kind the lamp invented by Sir Humphrey Davy, and thence called "the Davy-Lamp," is the most generally adopted, and on the whole the most effectual.

1119. The composition of the inflammable gas exuded from coal and present in coal-mines, is a matter too important to be passed over without notice. We append the latest and most careful analysis of specimens of this gas, collected by Mr. J. Hutchinson, from Gateshead and Killingworth colliery (Newcastle coal-field), the former from the five-quarter, and the latter from the Bensham, seam. The analyses are by Professor Graham.*

	Gateshead.	Killingworth.
Specific gravity	0·5802	0·6406
Carburetted hydrogen gas	94·2	82·5
Nitrogen	5·5	16·5
Oxygen	1·3	1·0
	100·0	100·0

* Mem. of Chem. Soc. of London, Vol. iii. p. 7.

1120. The proportion of carburetted hydrogen gas, or fire-damp, necessary to be mixed with atmospheric air, in order to render it explosible, is about one-fourteenth part. With this admixture there is danger, and the danger increases as more fire-damp is added, until the mixture reaches its maximum of explosibility, at which time the proportion varies from one-ninth to one-eighth. The risk of explosion is not so great when there is a larger quantity of the noxious gas, and when as much as one-fourth part of the mixture is composed of it, it will no longer explode, but begins to be inflammable.

1121. The principles involved in the construction of the *Davy-lamp* are simple, being first, that no mixture of the fire-damp with common air, however dangerous, conveys an explosion through tubes, the diameter of which is less than about one-eighth of an inch; and, secondly, that these explosive mixtures need a much stronger heat for their explosion than mixtures of common inflammable gas, since neither charcoal nor iron at a red heat will produce this effect, which requires, indeed, that iron be raised to a white-heat. Pursuing this discovery, Sir H. Davy found that the length of the small tubes, in which it was impossible to explode dangerous gases, was a matter of indifference, and that a metallic gauze, in which this length was merely the thickness of a fine wire, was quite sufficient for the purpose.

1122. It will be evident, therefore, that by surrounding the light of a lamp entirely by wire gauze whose meshes are sufficiently small, any explosion that may take place within the lamp will not be communicated to the outside, and the lamp may be safely carried where, otherwise, approach would be impossible. The size of the mesh for this purpose is from one-fortieth to one-sixtieth of an inch, and twenty-eight wires, or 784 apertures to the square-inch, are found a defence perfectly sufficient. It should, however, be distinctly understood that even such a lamp ought not to be used carelessly in any dangerous atmosphere; for, although perfectly secure when at rest, it seems certain that a rapid motion such as would be communicated by the swing of the arm during a hurried transit through the mine, might produce, and possibly has produced, an explosion. The main fault of the Davy-lamp, and indeed of all the other safety-lamps, arises from the small quantity of light diffused, and the consequent dislike acquired by the miners to its use. No contrivance, however perfect, can by possibility exclude the chance of accident, and the gross and almost inconceivable carelessness of men whose daily occupation leads them into the most imminent danger cannot be overcome, and can with great difficulty be understood by those not in the habit of constant communication with them.

1123. The quantity of carburetted hydrogen gas poured out into the workings of some mines is very considerable and constantly varying. Some seams of coal are much more full of gas than others,

and in working these, which are technically called *fiery seams*, it is not uncommon for a jet of inflammable air to issue out at every hole made for the reception of the gunpowder previously to blasting. In the celebrated Wallsend Colliery, in an attempt made to work the Bensham seam (an attempt terminated by a fearful accident), Mr. Buddle says, in evidence before a Committee of the House of Commons,* "I simply drilled a hole into the solid coal and stuck a tin pipe into the aperture, surrounded it with clay and lighted it, and I had immediately a gas light ; the quantity evolved from the coal was such that in every one of those places I had nothing to do but to set a candle and then could set a thousand fissures on fire ; the whole face of the working was a gas pipe from every pore of the coal." After a mine has been for some time opened, the gas drains off, at least partially, and the danger from this cause diminishes.

1124. But besides the gas thus steadily and constantly forced into the workings of a mine by a fiery seam of coal, there is always danger of sudden discharges as if from great reservoirs, rushing out from some fissure or small opening in large quantity and with considerable noise.

These jets are met with in mines perfectly ventilated, and they occur sometimes from the roof, sometimes from the floor of the mine, and still more frequently when small faults are reached in the course of working. Several collieries in the North of England are remarkable for constant discharges of this kind, which are collected and conveyed by a tube the nearest way to the upcast shaft.

2. *Iron Mines.*

1125. The vast preponderance in the value of the iron above that of every other metal obtained in England, and even above all of them taken together, renders it necessary to devote some space to describe the working of those ores from which the supply is chiefly derived.

The principal districts in the British Isles from which iron is obtained are three, the South Welsh, the South Staffordshire, and the West of Scotland.

The beds of ironstone being interstratified with the coal, and the sandstones and shales of the coal-measures, they are usually raised from the same pit as that by which the coal is extracted. The thickness of the ore, however, being generally only a few inches, it is worked in a manner somewhat different.

1126. Near Bilston, in the South Staffordshire district, there are as many as seven seams containing ironstone, all distinguished by technical names, but many of them not more than five or six inches in thickness, and alternating with claystones not containing iron. Two of the ironstone bands are thicker and more valuable than the rest,

* Parliamentary Report. Accidents in Mines, 1835; Minutes of Evidence, Qu. 2095.

and they, as well as all the others that are worked, lie beneath the ten-yard seam of coal in the district. The seams are, if possible, worked two together, the intermediate stuff being of no value, but removed to form a gallery, and afterwards piled up to support the roof when the ore has been obtained. The nature of the work is sufficiently simple; the miner usually lying on his right side, and striking with the pick to remove the ore and the intermediate clay. This method may seem a disagreeable one, but the galleries are cooler than the coal-mines at the same level, although they are also wetter and dirtier. The ironstone is of a dull brown or yellowish colour; it very often occurs in the shape of flattened spheroidal balls, and is traversed by cracks and fissures which have become filled with carbonate of lime. The centres of the spheroids often exhibit an organic nucleus.

There is considerable danger in working these mines from the occasional falling in of a portion of the roof, but they are usually almost entirely free from noxious gases.

1127. The iron district of South Wales supplies a large proportion of the whole amount of iron made in the British Islands. It is identical with the great coal-field of that district, the ironstone bands being always associated with the various beds which make up the carboniferous series.

The bands of iron-stone there, as in Staffordshire, are usually not more than a few inches thick, and the workings are, therefore, as narrow and low as possible. They are often inclined at a considerable angle, and this position is taken advantage of by working in levels which communicate with the lower part of the shaft by galleries run on the dip of the vein.

1128. "The distribution of the ore among the limestone, which in the Forest of Dean forms its matrix, is sometimes very remarkable. It lies in '*churns*', or '*pockets*,' as the miners term these deposits; and as the ore is cut away, natural pillars and arches of limestone are left supporting the roof in a variety of grotesque forms and combinations. The contents of the churns vary both in quality and quantity, producing a picturesque irregularity in the mine-works, strongly contrasting with the even courses of the coal strata."* Accidents are said to happen very frequently in these mines, from the miners neglecting to prop up the roof with timbers as they proceed.

The iron works in Glamorganshire and Pembrokeshire are sometimes so near the surface as to be obtained without a shaft or regular galleries. In other cases, they are worked from an adit level, which comes out to day on the side of a hill.

1129. The iron district of Scotland contains a vein of ore called

* First Report of Commissioners on Mines. Appendix, pt. ii. p. 4.

the black band, much richer than those ordinarily met with in South Wales or Staffordshire. This valuable stratum is extremely local, not being known to exist in perfection beyond a space of from eight to ten square miles; but similar deposits of inferior quality are sufficiently abundant. Black bands have been found also in various iron districts.

Although the true black band of Scotland is confined in its distribution, there are no less than four principal and valuable seams of ironstone in the Lanarkshire district, three of which are of very superior quality. These measure from fourteen to eighteen inches each in thickness, and when roasted yield from 60 to 70 per cent. of iron, requiring not more than six cwt. of limestone as flux, instead of from twenty to thirty cwt. (as the poorer and less fusible ores do) to produce the ton of metal. Some account of the statistics of the iron trade have been given in § 945, and the composition of various clay iron-stones in § 456.

3. *Salt Mines.*

1130. The salt-mines of Cheshire form so legitimate a branch of the great mining operations of our country, that they well deserve notice among the applications of mining principles now under consideration. These mines and the brine-pits of Worcestershire, not only supply sufficient salt for the consumption of almost the whole of England, but upwards of half a million of tons, for the most part the produce of the neighbouring county of Cheshire, are annually exported from the port of Liverpool.

The immense deposits of rock-salt from which this great supply is obtained, are strictly confined in England to the marls of the New red sandstone formation, and they are not universally distributed, being only met with in two or three counties skirting the Principality of Wales. In Cheshire the salt occurs in large quantities in the condition of an impure muriate of soda, and associated with a peculiar marl: it is sometimes massive, and sometimes exists in large cubical crystals, and the beds containing it usually alternate with considerable quantities of gypsum or sulphate of lime, although this latter mineral is not worked to profit.

1131. The appearance of the rock-salt is by no means of that brilliant character, nor has it the delicate transparency, and bright reflecting surface, which the reader may perhaps suppose characteristic of it. It is usually of a dull red tint, and associated with red and palish green marls; but it is still not without many features of great interest, and when lighted up with numerous candles, the vast subterranean halls that have been excavated present an appearance richly repaying any trouble that may have been incurred in visiting them.

In Nantwich and the other places in Cheshire where the salt is worked, the beds containing it are reached at a depth of from fifty to 150 yards below the surface. The number of saliferous beds in the district is five, the thinnest of them being only six inches, but the thickest nearly forty feet thick, and a considerable quantity of salt is also mixed with the marls associated with the purer beds.

1132. The method of working the thick beds is not much unlike that already described in speaking of the thick coal-seams of Staffordshire and Shropshire. The roof, however, being more tough, and not so liable to fall, and the noxious gases—with the exception of carbonic acid gas—totally absent, the works are more simple, and are far more pleasant to visit. Large pillars of various dimensions are left to support the roof at irregular intervals, but these bear only a small ratio to the portion of the bed excavated, and rather add to the picturesque effect in relieving the deep shadows and giving the eye an object on which to rest. The intervening portions are loosened from the rock by blasting, and it may be readily understood that the effect of the explosions heard from time to time, and re-echoing through the wide spaces, and from the distant walls of rock, give a grandeur and impressiveness to the scene not often surpassed. The great charm, indeed, on the occasion of a visit to these mines, even when they are illuminated by thousands of lights, is chiefly owing to the gloomy and cavernous appearance, the dim endless perspective, broken by the numerous pillars, and the lights, half-disclosing and half-concealing the deep recesses which are formed and terminated by these monstrous and solid projections.

1133. The descent to the mines is by a shaft, used for the general purposes of drainage, ventilation, and lifting the miners and the produce of the mine. The shafts are of large size in the more important works, and the excavations very considerable, the part of the bed excavated amounting in some cases to as much as several acres. Over this great space the roof, which is twenty feet above the floor, is supported by pillars, which are not less than fifteen feet thick.

The Wilton mine, one of the largest of them, is worked 330 feet below the surface, and from it, and one or two adjacent mines, upwards of 60,000 tons of rock-salt are annually obtained, two-thirds of which are immediately exported, and the rest is dissolved in water, and afterwards reduced to a crystalline state by evaporating the solution.

The mines, however, are not the only sources from which salt is obtained, and it is only since the year 1670, when the beds were discovered during an unsuccessful sinking for coal, that the actual rock-salt, as a mineral, has been dug out from the mine. Be-

fore that time, the chief supply was obtained from the brine-springs of Droitwich, near Worcester.

1134. Among the most remarkable of the rock-salt mines in Europe, are those of Altemonte in Calabria, Halle in the Tyrol, Cardona in the Pyrenees, and Wieliczka in Poland. These are all interesting, and each exhibits phenomena peculiar to itself, but I must not detain the reader with an account of individual mines.

The deposit of salt in the valley of Cardona, in the Pyrenees, is, however, too remarkable to be passed over. In this spot, two thick masses of rock-salt, apparently united at their bases, make their appearance on one of the slopes of the hill of Cardona. One of the beds, or rather masses, has been worked, and measures about 13 yards by 250, but its depth has not been determined. It consists of salt in a laminated condition, and with confused crystallisation. That part which is exposed is composed of eight beds, nearly horizontal, and having a total thickness of fifteen feet, but the beds are separated from one another by red and variegated marls and gypsum. The second mass, not worked, appears to be unstratified, but in other respects resembles the former, and this portion, where it has been exposed to the action of the weather, is steeply scarped, and bristles with needle-like points, so that its appearance has been compared to that of a glacier.

4. *Metalliferous veins, or lodes.*

1135. The nature and many of the phenomena of mineral veins have already been considered (see § 629, *et seq.*), and we do not propose in this place to recur to that part of the subject. We shall here only give a brief outline of mining operations so far as they are in any way dependent on Geological structure.

With regard to that department of Practical Geology which we are now considering, it must be confessed that at present the indications furnished of the existence of metalliferous ores by a consideration of the general order of superposition and age of the rocks of a district, are rather negative than positive, and scarcely do more than enable the Geologist to assert, that in such or such a spot there is no probability of the existence of productive veins. Still even this amount of knowledge is useful, and a more minute acquaintance with the disturbances and dislocations of the strata in a district already known to be metalliferous, is calculated to afford indications of the utmost value, and form a branch of Practical Geology, from the careful pursuit of which the most interesting results may be anticipated.

1136. By examining the beds of mountain streams, and the gravel or loose stones brought down into the plain country, a knowledge of the existence of metalliferous veins in a district may often be attained. By following up the indications thus afforded, an idea of

the actual position of the veins, and even of their extent and value, may also be acquired. This simple method was, no doubt, the one by which many of the richest veins were originally discovered, and it is still so far pursued, that sifting the gravel and sand of many rivers in metalliferous districts is to this day a profitable undertaking, and in some cases is the only kind of research pursued.

1137. "Stream-works," as undertakings are called in which this method of obtaining ore is pursued, are in our own country chiefly or entirely confined to the ores of tin, which, from their great specific gravity, are readily separated by the action of running water from the lighter sands and gravel with which they are associated. The ores of tin worked in the Island of Banca, in the eastern Archipelago, are entirely obtained in this way, and the quantity of ore brought down by the mountain torrents may be imagined when it is mentioned, that as much as 3,500 tons of tin have been exported annually from that island alone.

1138. In other cases, gold, platinum, and other metals, in a virgin state, are distributed in small grains in the sand, and this is, in fact, the chief source of the precious metals from many districts in Europe, Asia, Africa, and even some parts of America.

Some interesting observations have been recorded by the Russian mining engineers with regard to these auriferous sands. It has been remarked, that they rarely repose on granite or syenite, but usually on schistose rocks, near serpentines and hornblende rocks. They are also found, not in the recesses of the mountains, but principally forming plateaux parallel with and terminating the chain, or exhibited in the lower and broader part of the valleys. They are not continuous, and in certain localities the gold is more abundantly distributed than in others.

Generally the gold obtained by washings, and coming under the denomination of alluvial gold, is distributed in comparatively small proportion throughout the quartzose sand covering very extensive areas. But this is not always the case. In Siberia there appears to be a distinct epoch to which the auriferous alluvium belongs, and over such beds are others forming a capping often of clay and shingle containing no gold. It may easily happen in any other country as in Siberia, that there are alluvia of different ages obtained from rocks at a distance, or from the decomposition and disintegration of those *in situ*, some of them containing certain minerals, whilst others are totally deprived of them. Some attention therefore is required, not only in the selection of a spot which may be supposed to contain the proper mineral, but in finding out whether the gold is present at all, or in greatest abundance in any particular bed.

1139. In our own country the stanniferous gravels of Cornwall are not usually upon the surface, but are either covered with other gravel, or with clay, sand, or peat, which require to be removed before the fundamental rock is reached on which the tin-stones rest. The gravel when collected is thrown upon an inclined plane, upon which a fall of water is conducted, and then being worked about, the tin-stones, if of sufficient volume, and provided the force of the water is not too great, remain upon the inclined plane, while the lighter stones and earth are washed away.

1140. It is from this method of separating the ore that such

works have been called stream-works. They are of comparatively small importance now in reference to the general supply, but still afford employment to a number of the poorer miners.

As, however, such a source must be, at the best, doubtful and uncertain, and one which in most districts would soon fail, it becomes necessary that the gravel should be gradually traced up the bed of the stream, by whose rapid current it has been brought down, until the metalliferous fragments of rocks, increasing in number and volume, at last point to the spot where the outcrop of a vein at the surface has been the origin of the supply.

1141. This method of arriving at the actual position of the vein is called in Cornwall, *shoding* or *shoading*,* and is a method of great antiquity, being in fact an almost necessary preliminary to any regular mining operations. When the ore is thus discovered at its source, it is not difficult to determine whether it is a thick bed of gravel, a vein, or a mere lump of ore, and its direction and relations with the surrounding country may be more or less clearly made out.

1142. The early history of the Cornish mines, and the nature of mining operations in that country at the commencement of the 17th century are recorded in a very interesting manner by Carew.† "He first notices stream-works and lodes, and the opinion of the tinners that the tin-stones in the stanniferous gravels were derived from the lodes by the deluge. He next describes the process of shoding, which seems to have been then conducted much in the same manner in which it is now practised, and he notices that the shode for the lodes 'either lieth open upon the grasse or is but shallowly covered.' Having found this shode 'they next,' he says, 'sank pits of five or six foote in length, two or three foote in breadth, and seven or eight in depth, to prove where they may so meet with the load. If they miss the load in one place they sincke a like shaft (pit) in another beyond that, commonly further up towards the hill, and so a third and fourth until they light at last upon it.'" ‡

1143. If the lode thus discovered offered a fair prospect of success, the discoverer would usually associate others with him in the working, and the company of adventurers thus formed appointed a captain, whose duty it was to see that the men did their work properly, and who attended to the mine and to the pumps. The tools used were extremely simple, and consisted only of a pickaxe and shovel, but with these they would sometimes follow the lode to the depth of 40 or 50 fathoms, the miners being let down and taken up by a rope wound over a winch. In cases, however, where the hang or inclination of the lode was considerable, the miners are described

* The fragments of ore which by rain or currents of water are torn off from the lodes or veins of ore, are called *shoads*.

† Survey of Cornwall, by Richard Carew. (Reprinted 1769.)

‡ De la Beche's Report on the Geology of Cornwall, Devon, and West Somerset, p. 527.

as working to a convenient depth, when they sunk a shaft from the top "to admit a renewing vent, which notwithstanding, their work is most by candlelight." The loose work was kept up by timber, and the rate of progress appears to have been very slow, as we are told, "a good workman shall hardly be able to hew three foote in the space of as many weeks."*

1144. It will readily be imagined, that into pits thus sunk a considerable quantity of water would drain, and it is clear that this was an extremely troublesome and unmanageable difficulty, often inducing the abandonment of a valuable mine. The draining machinery is described as "composed of pumps and wheeles driven by a streame, and interchangeably filling and emptying two buckets and such like." In some cases, when the works were on a hill-side, canals were cut from the lode to the nearest convenient valley, but they are described as being "costly in charge, and long in effecting." And even where these difficult and expensive means were resorted to, the water would still have to be raised from such of the workings as were below the level of the valley, and a speedy limit would be put to all workings where the ore lay deep beneath the surface of the surrounding country.

1145. The description thus given of the superficial, and comparatively simple works of a former age, is applicable in a very considerable degree to more extended operations at the present day; for, although the introduction of improved machinery has tended to increase the facilities of working at great depths, the only difference in principle is the establishment of an improved plan of working adapted to the nature of veins of different kinds, together with that attention to ventilation necessary in all extensive underground operations.

1146. The indications on the surface that may be presented by a mineral vein, are not usually sufficient to attract general attention, and would in most cases be so entirely hidden by a coating of gravel and vegetable soil, as to exhibit scarcely any marks that would enable even the most experienced eye to recognise them. In the absence, therefore, of metalliferous gravels which can be traced up the course of a stream to a hill-side, and to the actual outcrop of a vein (and even then wherever many veins intersect), the question must often be determined more by experiment and tact, than by any distinct indications of the spot in which it will be most advisable to commence sinking, so that the greatest advantage shall be derived from the vein, supposing one there to exist. In cases where their actual presence is doubtful, but a probability appears of mineral veins being discovered, a series of experiments called in Cornwall "*costeaning*," is undertaken with the view of discovering the presence of a vein. This method of experimenting is derived from the supposition that the

* Carew, *ante cit.*, p. 10, 11.

veins in the district follow some general law, and the operators, selecting a convenient spot, commence by sinking a pit through the soil, and to a small depth in the rock. Of course the chances are many against immediate success, but in case they find nothing, the next step is to *drive*, or cut a gallery from the pit a short distance in opposite directions, at right angles to the direction of the lodes found in the neighbourhood. In this way it is possible that they may "cut the lode;" but if still unsuccessful, they remove a few fathoms in the direction of the galleries, and repeat the same process until they have either discovered the lodes, or give up the speculation in despair. In matters of this kind, although experience is often a better guide than abstract science, still there is no doubt that the person best able to bring his experience to bear will be one who is acquainted with the facts of Geology; and such an one will avoid many sources of error, because his conclusions will be founded on rational premises. The great secret of economical mining lies in the original adoption and proper carrying out of an uniform and well-digested plan of working, and the student may rest assured that such a plan can only be properly laid by an experienced mining engineer, who is able to add an acquaintance with Geological facts to sound practical and local knowledge.

1147. In the ordinary language of mining, pits open to the surface are called *shafts*; and in Cornwall those not open to the surface, but sunk from one gallery to another, have received the name of *winzes*. Horizontal galleries, excavated in metalliferous veins, are called *levels*, and those not in the metalliferous veins, *cross-cuts*; but that principal gallery, or tunnel, through which the drainage of a mine is conveyed to the surface at the lowest convenient spot, is denominated the *adit* or *adit-level*. All excavations horizontally are called *drivings*, those downwards *sinkings*, and those upwards *risings*.

1148. When the position of a mineral vein is ascertained, its direction known, and some reasonable conjecture made concerning its extent, thickness, and value, measures must be taken to obtain by subterraneous excavation the buried mineral, and for this purpose pits or shafts must be sunk, and galleries, or, as they are sometimes called, *levels*, must be driven, which prepare the way for the convenient extraction of the ore, and at the same time carry off, so far as may be, the water which either rises into the mine from springs or drains into it from the surrounding strata. Of such galleries, two sets must be driven at right angles to each other, and both horizontal, one being in the direction of the strike of the vein, and the other at right angles to that direction.

1149. The shafts sunk upon a vein are not always vertical to meet the vein, but are occasionally commenced at the outcrop, and, where the inclination is not very considerable, are continued in the substance of the vein itself. This is not, however, so economical a process as it may appear, for the difficulty of raising the ore is much

increased, and there are many practical reasons which often render it expedient to sink at some distance from the outcrop so as to meet the vein at a certain convenient depth.

1150. The act of sinking a perpendicular shaft downwards to a depth where it is calculated the lode should be cut, may seem to require little further skill than is necessary to determine correctly the spot on the surface where the work is to commence. But the process in this way is exceedingly tedious, and in a mine at work where many galleries already existing are to be traversed, much greater rapidity is desirable. In such a case, the shaft is sunk in several pieces, or, in other words, the sinking is commenced at the same time in several different levels, and no small skill is required so to lay out the work that the different portions of the shaft thus formed may exactly fit when they are connected together. An exceedingly small error of measurement in any one of these various and dark subterranean passages, would, in fact, be sufficient to throw the whole into confusion, but such an accident rarely happens, although works of the kind are common in the Cornish mines.*

1151. In the same way, to drive an adit from one point to another through many fathoms of country requires great skill, more particularly where, in order to save time, the work is commenced from both extremities. About a quarter of a century ago (in 1824) great complaints were made in Cornwall of the condition of these channels; and the necessity of attending carefully to the details of draining was insisted on, and the proper position of the adit pointed out by Mr. Carne. Owing to neglect in these matters, and to the want of good surface-draining, a large quantity of water pumped up from the deep mines, found its way back again among the workings, and this happened to so great an extent that since that period, greater attention having been paid to drainage, the quantity of water pumped is considerably diminished, although the mines have become deeper and more extensive; and in many mines, where great care has been taken with reference to this subject, the improvement has been very striking. Some idea may be formed of the extent of the drainage in mining districts from the fact that the various branches of the principal level in Cornwall, called the "*great adit*," which receives the waters of the numerous mines in Gwennap and near Redruth, measure on the whole about 26,000 fathoms, or nearly thirty miles in length. One branch only (at Cardrew mine) extends for nearly five miles and a half, and penetrates ground seventy fathoms beneath the surface. The water flows into a valley communicating with a small inlet of the sea, and is discharged about forty feet above high-water mark.

1152. In very extensive mines, such as are worked in Cornwall, it is

* De la Beche's Report, *ante cit.* p. 563.

necessary to have many shafts and a very considerable number of levels and cross-courses in order to carry on the general work of the mine. In such cases there is usually a principal shaft, of considerable size, sunk through as many lodes as possible, and communicating with all the galleries. This shaft is often double; one portion, called the engine-shaft, being used only to convey the water from the deep workings to the adit-level, and the other, the whim-shaft, to raise the ores to the surface. The two shafts are in these cases close together, and are united at convenient distances by short cross-cuts.

1153. It is always of importance to sink a shaft in such a way as to communicate directly with as many as possible of the lodes worked in a mine when, as is usually the case, several veins occur running in the same direction, and at no great distance from one another. In the Fowey Consols mine in Cornwall, as many as thirteen lodes are worked, and they are so near each other that one shaft (the Union) cuts through five of the lodes, and by means of a cross-cut at the sixty-fathom level, communicates with all the rest. The workings on different lodes are connected with each other by means of cross-cuts, so that the ores may be brought to the shaft, not only in the course of the lodes, but also at right-angles to their courses.

1154. These cross-cuts must be understood as having no reference to *cross-courses*, which are unprofitable veins traversing the lodes at right-angles. Great advantage, however, is sometimes obtained in mining by observing the peculiar circumstances connected with the traversing a lode by the cross-courses. Sometimes the latter are scarcely touched, being only crossed at right-angles in working the lode; but they are occasionally used to drive adits upon. The cross-courses are also generally connected with faults, and sometimes they heave the lode, and bar the progress of the miner, while at other times they tend to keep out the water accumulated in the old workings of a neighbouring mine. It will be manifest that a considerable amount of practical knowledge must be required to enable the miner to venture on any speculations in a matter of so much importance, and that an accurate notion should be had of the true mechanical condition both of the lode and cross-courses, before any undertaking that depends for its success on their mutual influence can be safely commenced.

1155. The lowest part of the engine-shaft, called the *sump*, is usually sunk a certain depth below the lowest workings, so that the drainage of the mine makes its way into it. It is, however, also important that each successive level should be separately drained in order that as little water as possible may descend to these lower workings. The water raised is delivered at the adit-level, and so escapes at the natural drainage-level of the district.

1156. The depth to which shafts are sometimes sunk below the

level of the surrounding country is sometimes very considerable, The Dolcoath mine, long celebrated for the depth and magnitude of its workings, reaches to more than 210 fathoms below the adit-level, which is itself 30 or more fathoms below some parts of the surface. The main shaft of the Fowey Consols is but little inferior, and there are several other mines both in Cornwall and elsewhere worked to a great depth. The Tresavean, the deepest mine in Cornwall, is now worked at a depth of upwards of 300 fathoms; and a machine has lately been erected there, by which the miners may be raised or lowered as much as 240 fathoms. The advantage of this machinery has already been greatly felt, and some contrivance of the kind would be found useful in all deep workings.

1157. In these cases the difficulty of mining is increased by the high temperature experienced in the workings, but the veins can hardly be considered to exhibit any very decided and uniform change in the value or amount of their contents, although in some cases ores of different metals seem to abound most within certain particular limits of depth. The increase of heat observed at considerable depths has been already mentioned (§ 37); but it seems to have some reference to the nature of the rock and the contents of the veins.

1158. The underground work of a mine depends chiefly upon the magnitude of the veins, and the value of the ore to be extracted. A vein once reached, either by the shaft or by the cross-cut carried horizontally from it, levels are driven at different depths (usually about 10 fathoms apart, but depending on the nature of the mining ground), and the whole horizontal section of the lode on each level is excavated by galleries. In many cases the lode not being more than a few feet in width, one such gallery is sufficient, and as it is only necessary to leave a passage wide enough to extract the ore, the levels at those places where the lode is narrow, or *nipped in*, are very narrow and confined. Where the lode is broader, and also rich, the open spaces are of course much larger, but there can scarcely be any rule in a thing so variable as a mineral vein, for the portion worth working, though small and with little ore in some places, may be several feet across in others and extremely rich, or the vein may be thin and rich in one place, and broad and comparatively poor in another; so that it may even be a question whether it is advisable to take that part out at all.

1159. Sir H. De la Beche adds, “These are matters on which the chief agents decide according to their skill and judgment. It is usual in mines, particularly those worked on a large scale, and for a continuance, not to take out all the ore which could be immediately got at if thought necessary, but to leave it here and there, to be worked as the general prospects of the mine may require, and to which the miners return if less ore is raised generally in the adven-

ture than could be wished. The ores thus left in various places are called the *eyes* of the mine ; and when it may be necessary, in abandoning the mine, or from any pressing circumstances, to remove them, it is termed '*picking out the eyes of the mine.*' In some mines these eyes are very valuable, and much skill and judgment are employed in so arranging the workings that a general good supply of ores may be obtained." *

1160. There are, however, distinct methods of proceeding when it is required to extract very large masses of ore, and in those cases where the horizontal section is too large to be at once excavated, pillars are left to support a roof, and cross-galleries are driven, intersecting one another. In order to avoid loss as much as possible, it is necessary in such cases to make the galleries lofty, and artificial support is given to the roof by timbering : but accidents can hardly be avoided when this method is carried on to a great extent.

1161. Connected with these operations of mining, and so contrived as to effect the required purpose in the best way, are the arrangements made for a proper supply of fresh air in the workings. The means of obtaining this are simple where there is no evolution of noxious gas, and they consist chiefly of making a proper use of the numerous shafts, and of the communications effected from shaft to shaft by the different levels or galleries. When these communications are properly made, currents are found to set in different directions, varying probably according to the variable temperature of the atmosphere at the surface and the uniformly high temperature under ground, and it is rare that any mechanical means are resorted to for ventilating the mine, except in such cases as where a level is in progress to communicate with a shaft. Generally speaking, the air becomes vitiated to such an extent that candles cease to burn brightly, long before it is sufficiently bad to destroy life ; and, in fact, it is so impossible to continue to work a mine in this state that accidents rarely happen.

1162. The veins of copper and tin, common in Cornwall, are for the most part not sufficiently thick to require any extraordinary method to be employed in extracting the mineral riches, but timbering is necessary to avoid the danger that would arise from the sinking in of the upper side of the vein.† In Derbyshire and Alston Moor, however, whence the chief supplies of lead ore in England are obtained, the veins traversing the mountain limestone swell out and become productive chiefly or entirely in one bed of limestone, and they there attain so great a thickness as to admit of being extracted

* De la Beche's Report, p. 561.

† The quantity of timber used annually in the Cornish and Devon mines is very considerable, and consists almost entirely of Norwegian pine. Sir Charles Lemon having counted the rings of annual growth on several of the trees, considers that the average age of the timber employed in the Cornish mines is about 120 years, and that it would require 140 square miles of Norwegian forest to afford a supply for these mines.—De la Beche's Report, *ante cit.* p. 573.

by methods very different from those necessary to be resorted to in the Cornish mines.

1163. There are certain local names given to peculiar forms of mineral veins in the North of England, which must be now explained, while referring to the mining operations of the district. The most common of these veins is the *rake* vein, which is a vertical crack or fissure, or rather a group of such fissures, parallel to each other, and frequently crossed at right-angles by small *pipe* veins; these pipe veins, the most important to our present purpose, are, in fact, horizontal expansions of the vein between certain beds of limestone, and are filled with the mineral matter which forms the matrix of the ore (barytes, fluor spar, calc spar, &c.).

1164. The appearance of one of the larger pipe veins is very curious, the vein being only rich where it expands on entering a particular bed of limestone. In the Alston Moor district there are many instances of this kind in the lead mines, and others are known in which rich ores of iron are worked, the masses of mineral substance being so extensive as to fill expansions of a vein, which when excavated leave vast subterraneous caverns.

1165. In order to obtain the ore from the vein, and break it into masses of convenient size, many processes have been formerly employed, which have almost all given way to that of blasting with gunpowder. By the Saxon Geologist, Werner, rocks were divided into five classes, according to their degree of hardness, the first being sandy and friable, and capable of being removed with the spade, and the second including those rocks of moderate hardness, such as coal, the Oolitic limestones, gypsum, shales, and slates, which require to be dislodged with the pick and removed in masses by the aid of levers and simple machinery. The third class of rocks includes those which are harder, but still not so hard as to strike fire with flint, and they may be removed partly by blasting, but chiefly with common picks, levers, and such simple machines. The fourth and fifth classes comprise rocks both hard and tough, and also those which are splintery, and they cannot be at all touched except with blasting, and even then sometimes scarcely repay the trouble and expense of working.

1166. After the ore has been detached from its matrix, it is necessary, of course, that it should be transported, in the most convenient way, to the bottom of the shaft, up which it is to be brought to the surface; and in large and well regulated mines, tram-roads are now commonly used, and the dimensions of the waggons, or corves (from the German *korb*, a basket), very carefully calculated; but in many mines, more especially those in South America, human labour is still employed, men, and even women, carrying on their heads heavy weights up the numerous and steep ladders that communicate with the upper ground. In France and Germany, and in

our own country, human labour is also employed, although chiefly in propelling, or drawing along underground galleries, the loaded waggons charged with the mineral produce of the mine.

1167. Great improvement has been effected of late years in the mode of transporting the ores underground, by the introduction of such small tramroads and waggons, instead of the old practice of wheelbarrows and planks; and the saving of expense thus effected is very great, amounting, in fact, to one half the former cost. Many extensive mines are provided with miles of subterraneous rail-road, and the advantage is greater, because for the most part there is a slight descent from the workings to the bottom of the shaft, to allow of a more complete system of drainage than could otherwise be attained.

1168. The ores are usually lifted by machinery from the bottom of the shaft to the surface, and in all extensive mining operations this machinery (the *whim*) is worked by steam-power; but although steam-whims are now common, horse-power is still used to some extent. The quantity wound up at one time varies, but sometimes amounts to half a ton, or more. In a very few instances inclined planes assist in raising the ore, but it is only under peculiar circumstances that they can be used with advantage.

1169. It is not possible to conclude this account of mining operations more appropriately than by a reference to the important subject of mining records, the value of which is often felt in England where, in consequence of the small interference of Government in any form, proprietors are allowed sometimes to neglect their own best interests to the ultimate injury of their neighbours' property.

1170. With regard to mining records generally, perhaps the following are those most important to be attended to, and copies of them should be preserved in some public place, with respect to every mineral vein worked in the country.

I. Accurate underground plans of the works on each level, and vertical sections through every vein and cross-course worked in the mine. To these plans should be attached notes referring to every fault and slip met with, its amount, direction, and effect on the vein, and the changes occurring from time to time in the vein, on passing into new ground, or traversing a dyke.

II. With regard to the veins themselves.

A. *The exterior relations of the vein.*

1. Its position, viz.: its distance from known points, its direction, and its inclination.
2. Its magnitude, viz.: its length and width at various points, the manner in which it terminates, and the way in which it ramifies.

B. *The internal state of the veins.*

1. The predominating ores and veinstones, and the order in which they are found in relation to one another.

2. The other ores and veinstones, and the circumstances under which they also occur, their frequency, size, richness, and the places where they are found.
3. The remaining internal circumstances of the vein; the fragments of rock found mixed with the substance of the vein; the mechanical condition of the filling up of the vein; the walls which separate it from the adjacent rock; and the nature of its adherence to the rock.

C. *With regard to the adjacent rock.*

1. Its nature and its Geological relations with the vein.
2. The inclination of the strata, if the rock is stratified, and the predominating joints and divisional planes.
3. The condition of the rock near the vein, and the greater or less amount of decomposition it has suffered; a statement of the metallic particles with which it is impregnated, and the fractures it has undergone.
4. The effect of the surrounding rock upon the vein, as well as that of the vein upon it.

D. *The relation of the vein under consideration with the other veins which it meets, and reciprocally.*

1. The direction and inclination of the veins at the point of meeting, the nature of the ores and veinstones, and the change, if any, that takes place at the intersection.
2. The peculiarities presented by smaller veins or threads, at their intersection with the principal vein, observing the following points:—
   a. If, after meeting, they continue together for some time.
   b. If the veins that meet the principal vein also cross it; or,
   c. If they are crossed by it.
   d. If they produce ramifications, break the vein, or are broken by it; disturb it, or have been disturbed by it; and the magnitude of all these effects, if they have been produced.
   e. If they intercept and stop the course of the principal vein, or change it into mere threads, or are themselves intercepted by, and swallowed up in it.

E. *The principal works done in the vein.*

Under this head should be noticed the excavations, and other trial works made in new ground, whether successful or not in finding ore, as well as all details connected with the regular workings. An account should also be given of the extent of each mining property and the name of the proprietor.

1171. The above intimation of the kind of information required concerning mineral veins is chiefly taken from Werner's "New Theory of the Formation of Veins," a translation of which into English was published at Edinburgh in 1809, and he adds:—"Such an account of mineral repositories requires much trouble, and a considerable time, to render it complete; but, from the very commencement, every step made in the labour will be profitable and useful of itself; while it is only by adding, from time to time, the new observations arising from our labour that we can hope to render it perfect. Such a description of a mining district would indeed form together a complete and instructive whole. If our ancestors had left us such documents for two centuries past, or even for half a century, of what advantage would it not have been to us? From

what doubts would it not have relieved us? With what anxiety do we not turn over the leaves of ancient chronicles in search of information, often very imperfect, obscure, and uncertain? With what pleasure do we not receive the least sketch or plan of some ancient mine? With what pains do we not rake up the heaps of rubbish brought out of old excavations, to discover pieces which may afford us some idea of the substances which were formerly worked out? Yet between these documents and those which we might obtain in the way pointed out in the preceding paragraphs, there is as much difference as between night and day. Ought it not to be an obligation and a duty, for us to collect and leave to future generations as much instruction and knowledge as possible on the labours carried on in our mines, whether it be in those that are still worked, or in those which have been given up."*

1172. But it is no less necessary that mining records should be preserved of those districts worked for coal and other mineral produce obtained from seams and beds, than that an account should be kept of mineral veins. We may quote the authority of the late Mr. Buddle, with reference to this subject, and in testimony that "the inconvenience and unnecessary expense which have frequently been occasioned in the Newcastle and other coal-fields, as well as the many fatal accidents which have happened from the want.

1173. The nature of the records, and the information which it is suggested by Mr. Buddle they might include, may be arranged under the following heads :—

1. The name of the proprietor of the surface and minerals.
2. The locality and extent of the property.
3. The number and description of the seams of coal and other minerals which it contains.
4. The thickness and quality of the several seams of coal; which of them have been worked; to what extent they have been worked; and why the working of any of them has been discontinued, or not commenced.
5. The winning of the colliery, viz. :—The number and position of the shafts; the difficulties met with in sinking, and the method of overcoming those difficulties.
6. The system of working; whether by pillars, by the long method, by panel work, or in what other way.
7. The dip and rise of the colliery. Description of the dykes, &c.
8. An account of the accidents that have happened by explosion.
9. The other accidents that have happened in the colliery, with their causes.
10. The system of ventilation practised.
11. General observations.

1174. To these may be added, in those districts where the ores of iron are bedded with the coal, an account (1) of the number, thickness, position, and extent of the seams of iron ore; (2) their relative value, and the percentage of metal obtained from them; and (3), the manner in which they have been worked, whether subordinately to the coal, or as a principal mineral product. Besides this,

* Werner's "New Theory of the Formation of Veins," translated by Dr. Anderson, p. 205.

very particular attention should be paid to the preservation of accurate plans of discontinued workings, with such references as may render it impossible to mistake the localities to which these plans refer. This latter is the more necessary, since, up to the present time, and even in cases where reports of the state of the underground workings have been preserved, they have often been found useless, owing to the impossibility of identifying the pits. This inconvenience was very strikingly exhibited in the drowning of the Hetton colliery in 1815, the water breaking in from workings which had not been relinquished more than 70 years. It should be very carefully noted in the description of relinquished workings, whether the pits are filled up or only scaffolded; and if the latter, at what depth. The compass bearings of all the workings should also be laid down, and the amount of magnetic variation recorded, that at any future time the accurate position of the underground excavations might be understood and ascertained at once from the plan.

It should also be remembered, that those who are desirous of assisting in this important work, should not be deterred from giving very full and detailed accounts from the apprehension of being considered too prolix and tedious, as on such a subject it is more excusable to say too much than too little.

Conclusion.

1175. The object in the preceding pages has been to offer to the student of Geology in systematic order those facts upon which the science is based, the deductions fairly made from them, and the more immediate and direct applications of them to practice. Commencing with the outlines of Chemistry, the only sure basis of natural knowledge and the alphabet of nature's language, I have endeavoured to explain in a general way those combinations of elementary substances most frequently met with, the forces acting upon matter and the laws by which the action of those forces is governed. From a very brief review of these points I have proceeded to exemplify them in an account of the existing condition of the earth's surface, and the changes now in progress tending to modify the physical features of various parts of the world, endeavouring to give a rational and true account of the various phenomena of the surface—the forms of continents and islands, the mountain and river systems, and generally the horizontal and vertical profile of our globe. All these facts and descriptions, which together form one great department of Physical Geography, are followed by a statement of atmospheric and aqueous action, going on constantly, and tending to alter the earth's surface by reducing inequalities; and this again is succeeded by an account of those subterranean movements, whose result is to add to inequali-

ties of surface already existing, or produce others in new directions. It is shown thus that there is no repose on or within the earth's surface, and that every day opens to a different scene from that which closed on the previous night.

Taking then another great department of natural science, I have endeavoured to explain and illustrate the nature of these solid materials, or mineral substances, of which the whole superficial crust of the earth is made up. The singular relations of form, and the various other physical characters of these substances are first dwelt on, and then the actual properties of the minerals themselves. This part of Geology possesses an interest and importance which no one can deny, and which requires special and careful study.

From the study of the materials we properly advance to that of the order of arrangement of these materials; but I have first enlarged on those very important proximate elements of Geology—the simple rocks, as distinguished from, or made up of, the simple minerals. These and their condition being explained, I have dwelt at some length on the structure and mechanical position of rocks, endeavouring to illustrate the true meaning and vast importance of those changes of condition, or phenomena of metamorphism, a knowledge of which is the key to all the higher speculations and many applications of Geology.

Advancing next to the description of rocks, I have illustrated this part of the subject by a brief account of the various stratified deposits, commencing with those of most modern date; and, while the various rocks were brought successively under notice, in order of the date of their formation, I have endeavoured to keep before the reader constantly the fact that group after group of different formations—some deposited under water, and some on land; some indicating the existence of a sea, and others of an estuary or a river—have occupied, one after another, districts now elevated high above the waves, and exposed to our researches. The reader will, thus, have perceived not only the fact of successive deposit, but also that the races of animals and vegetables have changed, making it clear that the greater portion of the earth's crust—so far as it is at present known—is made up of a series of strata overlying one another in regular order, and most of them containing abundant remains of organised beings.

I have also, from time to time, alluded to the fact that these beds have been disturbed and displaced by mechanical violence acting from beneath, producing various appearances of movement and dislocation, and connected with the more extreme cases of metamorphism and the outpouring of crystalline rock once existing beneath the surface in a state of igneous fusion.

Having thus completed the outline of Descriptive Geology, in

which, however, analyses of most of the rocks accompany the more general descriptions of them, I have, in the last two chapters, explained more immediately the mode of application of Geological knowledge to engineering and mining, as the natural and fit conclusion to the whole subject.

It only remains now to state, that in order to arrive at any useful practical result, the student must possess clear and definite notions concerning the fundamental facts of Geology, including under this head the nature of simple minerals, the laws of chemical combination and affinity, the nature of simple rocks, the position of rocks, and the nature of their disturbances, dislocations, and metamorphoses. Without this kind of knowledge all other is superficial and essentially unpractical—the student may be learned in what others have done, but he can make no useful observations or deductions that are at all to be depended on.

But let me explain what this means. I do not intend to say that in order to become a useful observer and to be capable of applying Geological knowledge to practical purposes the student must be a perfect adept, or master of all details and views of the science. This is by no means necessary. What is wanted is rather a philosophical knowledge of general principles—a knowledge obtained not merely by reading books or listening to lectures, but by reflection and actual observation. In this way only can the pursuit of any science be useful, and this is the way in which I would hope the present volume may be found available, and to some extent suggestive. I have endeavoured not merely to describe facts and quote the observations of Field-geologists, but rather to teach principles, leaving it to the reader to apply these principles and digest the facts, working out thus a sufficient education in the subject.

Geology is a science of induction derived from a multitude of observed facts and experiments—the experiments being, indeed, those which nature has made for us, and which it is our business to investigate. The facts observed are too numerous, too distinct, and too nearly connected to admit of any fear that the legitimate conclusions that have been drawn from them can ever be shaken. By the study of Geology, as of every branch of Natural History, the mind becomes stored with knowledge of the highest importance and the deepest interest; and in accumulating, arranging, and digesting this knowledge, we gradually become familiar with the generalisations to which it leads, and are at length able to make use of and apply it.

THE END.

APPENDIX.

EXAMINATION PAPERS IN GEOLOGY.

As a useful conclusion to this work, and also as illustrating the mode by which the Author has endeavoured to discover how far the knowledge of Geological students is satisfactory and real, a series of papers is appended which have been employed in the examinations on Geology held by him at various times at those public institutions with which he has been and is connected. The papers are given without alteration, arranged according to date, and thus many repetitions of questions may be observed, but this has been thought no disadvantage, as it illustrates the points which have seemed most important, or to which, in the course of the Author's experience, there has been most difficulty in obtaining satisfactory replies.

I.

KING'S COLLEGE, LONDON.

June, 1840.

GENERAL EXAMINATION IN GEOLOGY.

1.—Explain shortly the nature and objects of Geology, and the three principal branches into which, as a science, it must be divided.

2.—What is *stratification?* What do you understand by the expressions *stratified rocks* and *unstratified rocks?* Exemplify your meaning by applying the terms to some particular instance.

3.—How are strata identified? State the relative value and importance of the different methods by which they may be identified. What are *fossils?* In what kinds of rocks are they found? What kind of remains of organised beings are most abundant, most characteristic, and therefore most important?

4.—In what strata, or group of strata, are the remains of mammalian animals most abundant? What ways are there of ex-

plaining the fact that they are chiefly confined to the less ancient deposits? Can you mention any instances in which such remains do occur in strata of great relative antiquity?

5.—The remains of animals of the lizard tribe (or *Saurians*) are extremely abundant in one stratum which they characterize: mention the name of this stratum, and give some account of the more remarkable forms of these animals.

6.—Give some account of Tertiary formations generally. How are they sub-divided, and for what reason? What are the local names for the principal English groups? To which of Mr. Lyell's sub-divisions do they respectively belong?

7.—Indicate, by means of an ideal section, the principal sub-divisions of the Secondary system, including in that title all fossiliferous rocks below the Tertiaries. What is the most remarkable fresh-water group among the Secondary rocks, and in what part of England is it chiefly developed?

8.—The Oolitic—New red sandstone—and Carboniferous systems are each of them remarkable in England for some products extremely important and useful to man. What are these products, and where are they respectively found in most abundance and greatest excellence?

9.—Explain the following terms made use of in Geology, viz:—*dip, strike, fault, anticlinal* and *synclinal axis, conformable* and *unconformable stratification.* Which of these indicate the action of a disturbing force? What was the probable nature of such force? Mention instances of the action of subterraneous forces at the present day.

10.—Enumerate various occasions on which a knowledge of Geology may be useful to the practical man. Explain the nature of Artesian wells. Refer, if you are able, to the various Geological causations by means of which water rises to the surface in natural springs.

11—What are the more abundant ores of metal worked in this country? Give such particulars as you can explaining the usual conditions under which are found (1) Iron, (2) Lead (3) Tin. Mention also the different methods of obtaining the metals which are most common.

12.—Explain the nature and probable origin of Coal. In what formation is it most abundant in this country? Give some account of the method of working it—of the peculiar dangers to which the miners are exposed, and of the contrivance by which they may secure themselves.

II.

KING'S COLLEGE.

June, 1841.

GENERAL EXAMINATION.

1.—Define Geology, explaining—
a. the meaning of the word ;
b. the immediate objects of research in the science of Geology ;
c. the various modes in which it may become useful to practical men.

2.—*a.* Distinguish between *alluvium* and *diluvium*.
b. Under what circumstances do either of them occur ?
c. To which of them is the gravel of England referred ?
d. Mention any observations by which various beds of gravel, may be identified, and shown to have proceeded from one spot or one point of the compass.
e. What kind of fossils are chiefly met with in gravel ?

3.—*a.* What do you understand by *stratification ?*
b. Mention instances of stratified and unstratified rocks.
c. What is the nature of the evidence on the strength of which it is assumed that stratified rocks are for the most part of aqueous and unstratified rocks of igneous origin ?
d. In what part of England are unstratified rocks more common than stratified ?
e. Explain the meaning of *dip* and *strike.*

4 —State, shortly, the steps in the argument by which it may be proved to a person ignorant of Geology, that each well-defined fossiliferous stratum occurring in England was formed with comparative slowness at the bottom of water : — that it is utterly impossible that any two, as, for instance, the mountain limestone and lias, should have been formed contemporaneously, but that each was deposited in its place successively, in many cases long after those beds found below it, and long before those seen lying above it.

5.—*a.* What beds are included under the denomination, Tertiary formations ?
b. How have they been subdivided—
1. with reference to their fossil contents ?
2. with regard to local differences of appearance ?
c. Mention the names that have been given to British Tertiaries, and the Geological period to which each is referred.
d. Mention, also, the kinds of fossils most remarkable and most abundant in each.

e. 1. With which of the English Tertiaries are the beds in the neighbourhood of Paris contemporaneous ?

2. For what fossils are the Paris beds most remarkable ?

6.—*a.* Express by means of an ideal section, the principal subdivisions of the Cretaceous and Oolite systems, as they are known in England.

b. What peculiar genera of fossil shells are most remarkable in these beds, and in what do they differ from the shells of animals living in the present seas ?

c. Are you aware of any general fact with regard to the extinction of species that first attracts attention in examining the fossils of the Cretaceous system ?

7.—*a.* In what respect does the group of strata, denominated *Wealden*, differ from the other groups of the Oolitic and Cretaceous systems ?

b. Mention a few of the more remarkable fossils characteristic of the Wealden beds.

8.—*a.* 1. In what formations is Coal found, and

2. With what mineral is it associated ?

b. What are the chief fossils of the Coal ?

c. Give some account of the probable origin of Coal.

9.—*a.* What is meant by the term *metamorphic* rocks ?

b. 1. Quote some examples of rocks of this kind.

2. Show in what way, and

3. To what extent they form a link between fossiliferous and non-fossiliferous rocks ?

10.—*a.* It is concluded by Geologists that there have been disturbances caused by, or connected immediately with, volcanic eruptions and earthquakes at all periods of the earth's history. State some of the more striking facts from a consideration of which this conclusion is warranted.

b. Are you aware of any actual experiments which identify ancient basalt with recent volcanic products ?

11.—*a.* Explain clearly the difference between *stratification, joints* and *cleavage*, under the following heads :—

Stratification and *joints*.

Stratification and *cleavage*.

Joints and *cleavage*.

b. In what way can *joints* and *cleavage* be accounted for, when they occur in metamorphic rocks ?

12.—*a.* Explain the meaning of the word *fault*.

b. Show that in the case of the coal strata, the existence of faults is of great economical importance.

c. What do you understand by *anticlinal* and *synclinal axes* ?

13.—*a.* What are the different kinds of stone used in building?
b. State some of the advantages and disadvantages of each.
c. By what methods of examination may the value of a stone for building purposes be best discovered?
d. 1. Mention a few of the principal building stones in England, and
2. The geological position of each.

14.—*a.* What is a *mineral vein?*
b. What proof is there that mineral veins are of various ages?
c. Are you aware of any very general law with regard to the direction of mineral veins?
d. In what direction are metalliferous veins most likely to be met with?
e. Mention the principal metals found in England.
f. Mention, also, the formation in which each most usually occurs.

15.—*a.* Explain fully the nature of Artesian wells.
b. In what way can the existence of springs be explained, where it is impossible that the principle of Artesian wells could apply?
c. Under what circumstances is the drainage of land likely to be most effective?
d. What are the usual Geological phenomena of Fen districts?

III.

KING'S COLLEGE.

June, 1842.

GENERAL EXAMINATION.

1.—State fully what you suppose to be the meaning of the word Geology. Explain what are the objects of research when a person endeavours to make himself acquainted with the geology of a district and mention the general results which the study of Geology as a science may be expected to realise.

2.—Explain the origin of Valleys: viz. (1) Valleys of Elevation, (2) Valleys of Denudation.

3.—Mention the causes that have been assigned to account for the accumulations of gravel in various parts of England and Northern Europe. Enumerate also a few of the animals whose remains have been found most commonly in this deposit.

4.—What do you understand by *stratified* and *unstratified* rocks? In what way do the latter usually make their appearance?

5.—Explain the cause of the trough or basin-shape of Tertiary formations. Give some account of the older Tertiary rocks of England and France.

6.—In what respect do the calcareous beds of the Cretaceous group differ from those of the Oolites? Mention the most valuable economic products of the Oolite, New red sandstone, and Carboniferous formations respectively.

7.—What are the usual limits of the thickness of workable beds of Coal in England? Explain the different methods employed to obtain coal known as the *long-wall* and the *pillar and stall* method. What are the advantages of each, and the local circumstances which prevent the most economic from being made use of in some districts?

8.—State clearly the distinction between a bed containing *mineral produce* and a *mineral vein*, and illustrate your explanation by referring to examples in various parts of England.
What are the most important Metals found in England, and where do they chiefly occur?

9.—Explain the Geological use of the word *fault*, and show in what way the occurrence of faults is connected with the phenomena of springs. If a well be dug through clay into sand, state clearly the conditions that are necessary in order that water may rise through the clay and form an Artesian spring.

IV.

KING'S COLLEGE.

June, 1843.

GENERAL EXAMINATION.

1.—Define and illustrate the following terms used in Geology, *dip, strike, fault, anticlinal axis* and *fossil*.

2.—Write down the principal subdivisions of the Secondary rocks in England beginning with the New red sandstone group, and mention any remarkable organic remains that you consider to characterise the successive groups.

3.—What are the principal Tertiary strata met with in England and where do they occur?

4.—To what cause do you attribute the fact that almost all the Sedimentary rocks are in a position inclined more or less to the horizon? Are you acquainted with any recent phenomena which assist in explaining the nature of the disturbances met

with in the older rocks? Mention any effects similar to those observed in the older rocks, but which are due to the action of modern causes.

5.—What is the nature of *mineral veins?* Give such account as you are able of the theories that have been proposed to account for the phenomena of metallic lodes.

6.—Explain fully the difference between a *metallic vein* and a *bed of coal*. Which are the principal Coal-fields in England? To what accidents are coal-fields more particularly liable, and how has it been attempted to avoid them?

7.—What are the principal building-stones used in England, and in what Geological formations do they respectively occur?

8.—Explain the nature of land-springs, fault-springs, and intermittent springs, giving an example of each.

V.

KING'S COLLEGE.

June, 1845.

GENERAL EXAMINATION.

1.—Give a general account of the nature and objects of Geology and the different ways in which it has been applied to practical purposes.

2.—Define *stratification*. Explain what is meant by *conformable* and *unconformable stratification*. What is a *fault*, and what an *anticlinal axis?*

3.—Explain the meaning and present use of the term *fossil*. What kinds of fossils are most abundant, and in what way are they especially useful in Geology?

4.—Mention any fossils that you may know which are characteristic of particular formations.

5.—Write down in order a list of the chief groups of strata, and the name by which each is distinguished.

6.—What are the principal rocks not usually found stratified? Distinguish between *granitic*, *basaltic*, and *metamorphic rocks*.

7.—Explain the difference in principle between mining for metallic ores in veins and mining for coal.

8.—How is salt found in nature? where are there extensive salt-mines? and what is the geological nature of the associated rock?

VI.

COLLEGE FOR CIVIL ENGINEERS, PUTNEY, SURREY.

May, 1845.

GENERAL EXAMINATION.—ELEMENTARY GEOLOGY.

1.—What is the object of Geology, and of what nature are the observations and facts on which the science of Geology is founded.

2.—What is the meaning of the following terms used in Geology, namely :—*dip, strike, anticlinal axis*, and *fault*.

3.—What are the principal groups of strata, and the order in which they are arranged on the earth's surface.

4.—Mention, so far as you are able, the chief characteristic peculiarities of the *mountain limestone*, the *oolitic limestones* and the *chalk*.

5.—What is meant by a river delta? and what proof is there of accumulations of mud formed at the mouths of rivers where no delta occurs?

VII.

HONORABLE EAST INDIA COMPANY'S MILITARY SEMINARY AT ADDISCOMBE.

September, 1845.

GENERAL EXAMINATION.

1.—Of what nature are the materials of which the earth's crust is made up, and in what condition are they generally found; distinguishing between crystalline minerals and rocks, and using the latter term in its Geological sense?

2.—What are the principles of Geological classification? Write down the Geological sequence of rocks in England, and the most remarkable *fossils* of each group.

3.—Under what circumstances of association with other rocks is coal generally found? How is its presence generally known on the surface?

4.—What kind of rock is *basalt?* Is the presence of basalt any guide in determining the age of other rocks?

5.—Of what Geological age are the *laterite, kunkur*, and *regur*, or cotton soil of India, and what is the general character of each of these rocks?

6.—Explain the nature of Artesian springs, and the Geological condition of the districts in which such springs may be expected to occur.

VIII.

KING'S COLLEGE.

March, 1846.

SCHOLARSHIP EXAMINATION.—MINERALOGY AND GEOLOGY.

1.—What are the physical characters of a *mineral* ?
2.—Describe a *simple mineral.*
3.—State the component minerals of granite.
4.—Define the terms *dip, strike,* and *fault.*
5.—Explain what is meant by a *geological section.*
6.—Mention the kind of fossils most characteristic of the Coal-measures.

IX.

KING'S COLLEGE.

June, 1846.

GENERAL EXAMINATION.

1.—What do you understand by the term *stratification* ? Mention an example of a distinctly stratified rock, and of some unstratified rock. Explain the nature of the changes which have affected stratified rocks since their first formation. Define the terms *dip* and *strike, fault* and *anticlinal axis.*
2.—What are *fossils* ? Mention in what formations fossil reptiles are most remarkable and most abundant. What parts of animals and vegetables are found fossil ; and in what condition are fossils found ?
3.—Write down the main sub-divisions of the *Palæozoic* period.
4.—Distinguish between *stratification* and *cleavage,* and give some account of *metamorphic action,* mentioning both its nature and some of the results.
5.—Explain the difference between Land springs and Artesian wells. Explain the cause of the latter.
6.—In what Geological formation do we find beds of Coal ? State the practical difference between working coal and obtaining metallic ores from mineral veins.
7.—What are the most important Metals found in England, and where do they occur ?
8.—State some of the facts that have been adduced in proof of the hypothesis of the central heat of the globe.

X.

H.E.I.C. MILITARY SEMINARY, ADDISCOMBE.

Sept. 1846.

GENERAL EXAMINATION.—MINERALOGY AND GEOLOGY.

1.—Explain the general structure of the earth's crust as made known by the study of Geology. Explain the meaning of a *Geological map* and *Geological sections.*

2.—What do you understand by the terms *dip* and *strike?* If a bed dips to the east, what is the direction of the strike?

3.—Under what circumstances is it likely that water will be obtained in a district whose Geology is known, by sinking on the Artesian method. Show in what way a knowledge of the Geological structure of the district assists in arriving at this conclusion.

4.—Mention the most remarkable coal-districts at present known in India.

5.—In what way is a knowledge of fossils useful in Geology? What kind of fossil remains must be considered most generally useful for such purpose?

6.—What is meant by *cleavage* in Mineralogy and Geology? Explain also the nature of *isomorphism,* and mention any groups of isomorphic minerals.

7.—What is *basalt?* and where is there to be met with the most remarkable development of tabular basalt? Has the presence of basalt any influence on the industrial resources of a country?

8.—Under what circumstances are diamonds obtained in India?

XI.

KING'S COLLEGE.

June, 1847.

GENERAL EXAMINATION.

1.—Illustrate the nature of those modifications of the earth's crust produced by the action of water in motion. Mention the most remarkable river Deltas in the world.

2.—What is an *earthquake?* How are earthquakes connected with volcanoes and volcanic disturbance?

3.—What is the ordinary condition of the materials of the earth's crust? Distinguish between *igneous rocks, aqueous rocks,* and *metamorphic rocks;* mentioning examples of each.

4.—Explain the terms used in Geology with regard to the position of rocks, namely:—*dip, strike, anticlinal* and *synclinal axes, conformable* and *unconformable superposition, fault.*

5.—Write down the general sequence of stratified rocks in England.

6.—What are *fossils?* Of what use are they in Geology? And what do you understand by the statement that "fossils are characteristic of formations?"

7.—Explain the phenomena of Artesian springs. Give an example of some successful sinking for water by the Artesian method?

XII.

PUTNEY COLLEGE.

July, 1847.

GENERAL EXAMINATION.—MINERALOGY AND GEOLOGY.

1.—What are the principal characters of *quartz?* How do you determine *quartz* from *carbonate of lime?*

2.—What minerals represent the scale of hardness?

3.—What is meant by *cleavage* in Mineralogy and Geology? Explain the nature of *isomorphism,* and mention any groups of isomorphic minerals.

4.—Define the terms *dip, strike, fault,* and *anticlinal axis.* Explain the meaning and use of *Geological maps* and *sections.*

5.—Write down the various groups of stratified rocks found in England in their order of superposition.

6.—Give a general account of the Oolitic series of rocks, mentioning some of the localities where valuable building stones are obtained?

7—.What is Granite? In what does granite differ from basalt? and what are the characters common to the two?

8.—Explain the nature of intermittent springs, and the mode in which they are supposed to originate?

9.—What is Coal? Where are deposits of coal chiefly found? What is the difference between a *bed* or *seam of coal* and a *mineral vein?*

10.—Under what Geological conditions may drainage be effected for works erected on stratified rocks?

XIII.

H.E.I.C. MILITARY SEMINARY, ADDISCOMBE.

September, 1847.

GENERAL EXAMINATION.—MINERALOGY AND GEOLOGY.

1.—What are the mineral substances which chiefly compose the earth's crust? What are the elementary substances from which they are derived? What are the methods that have been suggested as most useful in classifying minerals?

2.—What is the composition of Granite? and what are the essential points of difference between granite and basalt?

3.—Explain the nature of *stratification.* What do you understand by the expressions *dip* and *strike* of beds? Define the terms *conformable* and *unconformable superposition.* How does *cleavage* differ from ordinary stratification?

4.—Give some account of the geographical position of the Coal-beds of India. Mention also the most important Coal-districts in other parts of the East.

5.—Explain the nature and use of *Geological maps* and *sections,* stating the advantage of colours and the general geological meaning of certain colours?

6.—Under what circumstances may Land springs be expected in a district? What are the Geological conditions requisite for the existence of intermittent springs?

XIV.

KING'S COLLEGE.

March, 1848.

SCHOLARSHIP EXAMINATION.

1.—What are the principal characters of *quartz?*

(*a*) General form of the crystal.
(*b*) Fracture.
(*c*) Hardness.
(*d*) Action of acids.
(*e*) Action of blowpipe *per se.*

2.—Name some of the substances which quartz will readily scratch.

3.—Name the principal combustible minerals, and any properties peculiar to them, such as easy fusibility, odour, &c.

4.—What minerals resemble Gold? How is gold distinguished from such minerals in crystalline form, hardness, or specific gravity, or when acted upon by the blowpipe or by acids?

5.—What are the chief mineral components of stratified rocks?

6.—How are rocks classified? Write down the sequence of fossiliferous rocks in England.

7.—Under what circumstances may a steady supply of water be obtained in a gravel district? What are the Geological conditions favourable for the existence of Artesian wells?

8.—Explain the origin of valleys, viz.:—
(1.) Valleys of elevation.
(2.) Fault valleys.
(3.) Valleys of denudation.

XV.

KING'S COLLEGE,

June, 1848.

EXAMINATION IN DESCRIPTIVE GEOLOGY.

1.—Explain simply the nature of Geological inquiries and the means by which Geological facts are determined.

2.—How are the materials which compose the earth's crust usually arranged? Explain the nature of *stratification* and the structure of unstratified rocks.

3.—What is *cleavage?* Explain the difference between *cleavage* and *stratification.* What is *jointed structure?*

4.—Describe the characteristic peculiarities and most remarkable groups of *fossils* of the Oolitic series of rocks as met with in England.

5.—Write down the complete series of fossiliferous strata as far as English Geology is concerned, mentioning characteristic species or groups of fossils.

6.—Where are the chief Tertiary rocks of England found? What is the mineral ingredient that chiefly prevails in the Older tertiary rocks of England?

7.—What deposits, or groups of deposits in England are remarkably important (1) for building material, (2) for mineral fuel (3) for salt?

8.—Give a general section across England, from the coast of Suffolk to the Welch mountains?

XVI.

KING'S COLLEGE.

June, 1848.

EXAMINATION IN PRACTICAL GEOLOGY.

1.—In what way are soils of various kinds obtained in different parts of the earth? Explain the relation between a soil and the subjacent rock.

2.—Explain the advantage of deep draining and the Geological conditions under which it is likely to be useful.

3.—Explain the Geological structure upon which depends the existence of water at moderate depths beneath the earth's surface, and show when and how far water is capable of being obtained for the use of man by sinking wells.

4.—What are the qualities valuable in Limestones required for building purposes? Mention the chief limestones found in England, their Geological position, peculiarities of structure, and relative value.

5.—In coal-mining explain the action of faulted structure in damming back water.

6.—Explain fully the theory and construction of the *Davy Lamp*, and the circumstances under which its use is desirable or necessary?

7.—Show in what way and to what extent the timbering that will be required in a mine depends on the Geological conditions of the surrounding and adjacent rocks.

8.—Define what is meant by a *mineral vein*, or *lode*. What is the prevailing direction of right-running tin and copper lodes in Cornwall? What is a *cross course?*

XVII.

PUTNEY COLLEGE.

July, 1848.

GENERAL EXAMINATION, MINERALOGY AND GEOLOGY.

1.—What are the most abundant of the mineral substances which make up the solid portions of the earth's crust? Are they simple or compound bodies? Are any of the supposed elementary substances more widely distributed than others? Mention the elementary substance most universally present.

2.—What are the relations of *form* presented in the case of ordinary minerals? Explain the nature and limits of those regular forms called *crystals.* State how far crystalline action on a large scale is supposed to affect masses of mineral matter important from their large dimensions and great abundance.

3.—Give examples of minerals in which hardness, colour, odour, and electricity respectively are known to be characteristic. In what way may iron pyrites be easily distinguished from copper pyrites?

4.—Explain that peculiarity of structure called *cleavage.* Explain the difference between *stratification* and *cleavage,* and define also the expression, *jointed structure.*

5.—Define the following terms used in Geology, viz., *dip, strike, anticlinal axis, dome, fault, valley of elevation, valley of denudation.*

6.—What are the subdivisions of the stratified rocks in England? Explain the nature of *fossil organic remains,* and the use of fossils in the identification of rocks.

7.—For what mineral substances of economic value are the following groups of rocks remarkable in England, viz., the Carboniferous series; the New red sandstone series; the Oolitic series?

8.—What are the chief facts observed that prove the deposited rocks to have been exposed to the action of disturbing forces.

9.—How and whence are soils derived? Explain the relation existing between soils and the subjacent rock.

10.—What are the two great subdivisions of mining, and how do they relate to Geological structure? State distinctly the difference between a *stratum* or bed and a *mineral vein.*

11.—Whence are the ores of the following metals chiefly obtained, viz., copper, tin, lead, zinc, gold, silver? Mention the most common ores of these metals, and the localities in England where they are chiefly worked?

12.—Under what Geological conditions is it possible to obtain water from the earth by sinking wells? What is the essential difference between land springs, fault springs, and Artesian springs?

13.—Describe the principal points to be noticed by a Geologist between Hythe and Folkestone.

14.—Draw a rough section of England from east to west, naming the different strata in the order of their occurrence.

XVIII.

KING'S COLLEGE.

March, 1849.

SCHOLARSHIP EXAMINATION—MINERALOGY AND GEOLOGY.

1.—What are the physical characters of minerals? Explain the difference between *colour* and *streak.*

2.—What minerals represent the scale of hardness? Are intermediate degrees used? Give an example.

3.—What is the common crystalline form of *fluor spar,* and what different crystalline forms can be obtained from fluor spar by cleavage?

4.—What are the principal characters of *calcareous spar?*

a. Primitive form.
b. Fracture.
c. Hardness.
d. Action of acids.
e. Action of blowpipe.

5.—What minerals resemble the *diamond,* and how can they be distinguished?

6.—What are the materials of which the great mass of the earth's crust is made up? Is there evidence of order in their arrangement? and if so, give some proof. Are there found mixed up with the mineral substances any remains of animals and vegetables? and if so, mention the usual mineral condition of such bodies.

7.—Are there any marks of mechanical disturbances traceable amongst the masses of matter which form the greater part of the earth's crust? and if there are, mention some of them. What marks of change of other kinds (not strictly mechanical) can be traced in the rocks in any part of the British Islands that you may be familiar with?

8.—Explain the phenomena of springs of various kinds, as dependent on the Geological structure of the district in which they occur.

9.—Mention some of the advantages of Geological knowledge to the engineer.

10.—Prepare an ideal section, illustrating the sequence and position of the various rocks occurring in England between London and Brighton.

XIX.

KING'S COLLEGE.

June, 1849.

EXAMINATION IN DESCRIPTIVE GEOLOGY.

1.—Explain the nature and use of *Geological map* and *sections* in illustrating the structure of the earth in a given district.

2.—Mention the chief Mineral substances of which the stratified portion of the earth's crust is made up, and the state of mechanical aggregation in which they are usually found.

3.—Describe fully the development of the cretaceous series of rocks in England, and the relations they exhibit to the underlying and overlying series.

4.—Explain and illustrate the use of fossils in Geology.

5.—Mention the principal facts concerning the distribution of basaltic and other volcanic rocks in England.

6.—What do you understand by the term *metamorphic rocks*. Illustrate the phenomena of *metamorphism* in the case of common roofing slate?

XX.

KING'S COLLEGE.

June, 1849.

EXAMINATION IN PRACTICAL GEOLOGY.

1.—Give as complete an account as you are able of the Geological position, mineral character, economic use and qualities of the Bath and Portland Oolites.

2.—Describe the mineral character and usual position of roofing *Slate,* and the mode of working adopted in slate-quarries.

3.—Explain the derivation of soils, mentioning the way in which the depth, texture, and fertility of a soil is dependent on the parent rock.

4.—In coal-mining explain the method of ventilation by splitting the air, according to the practice in the Newcastle coal-field, and the extent to which the splitting may be carried.

5.—What is the Geological position of the lead and zinc ores commonly worked in Great Britain, and state where these ores chiefly abound.

6.—Explain the usual conditions under which Gold is found in various parts of the world.

7.—Describe the nature of *surface-drainage* and the phenomena of *land-springs.*

XXI.

PUTNEY COLLEGE.

July, 1849.

GENERAL EXAMINATION IN MINERALOGY AND GEOLOGY.

1.—Describe the general nature of the materials which make up the earth's crust. Give the usual names of those which are most abundant; their strict natural history definition; the proximate and the ultimate elements of which they are composed.

2.—Mention the Metals which are most abundant, the form in which each is most usually present, the places whence the ores are chiefly obtained, the nature of the ore most frequently found in each locality, and the usual yield of each common ore.

3.—Explain the nature of the Diamond, the Ruby, and the Topaz. Mention the chief physical qualities of each, and the localities in which each substance is most commonly found.

4.—What is understood in Geological language by *denudation?* What is a *valley of denudation?* What are the denuding forces at present acting, and where are their chief results likely to be found? What is the difference between *denudation?* and *erosion?*

5.—Write down the list of deposits which make up *the Palæozoic series*, stating the places where each division of the series is best represented, and the characteristic fossils of each.

6.—What portions of the Secondary series of rocks in England are most important as building material?

7.—Mention the rock from which common Salt is chiefly obtained in England, and its Geological position. Which of the salts of lime is usually found with common salt, and in what form does it usually appear?

8.—What method is adopted in the vicinity of Newcastle-on-Tyne to obtain the largest quantity of round coal from a deep pair of pits on a large estate? Mention the chief contrivances for ventilation, and the mode commonly adopted to obtain a strong draught of air.

9.—Explain the nature of *faults* and *dykes*, and their effect on the practical working of any bed or vein.

10.—In what parts of England are Igneous rocks of a porphyritic character most abundant? What relation exists in England between the presence of igneous rock of this kind, and the existence, the direction, and the contents of mineral veins?

11.—What are the conditions under which Water falling from the clouds, sinks beneath the earth at one point, and reappears at a distant point in springs? Explain also the circumstances under which Artesian springs may be obtained artificially.

12.—Mention some of the theories that have been suggested to account for the phenomena already distinctly observed with regard to the structure of the earth.

XXII.

H. E. I. C. MILITARY SEMINARY, ADDISCOMBE.

September, 1849.

GENERAL EXAMINATION.—MINERALOGY AND GEOLOGY.

1.—What is a Volcano? Mention some facts proving a connection between volcanic and earthquake action. Give examples of volcanic phenomena in districts where there is now no true volcano. Mention examples of recent alteration of level in volcanic districts.

2.—Mention some instances of aqueous action tending to modify the existing coast line of England. Explain the nature and cause of river Deltas.

3.—Explain the nature and meaning of Crystalline structure. Give an example of some crystalline mineral, and mention its distinguishing character.

4.—What are the Minerals used in describing the relative hardness of minerals? Distinguish between the Colour and Streak of Minerals.

5.—How are Rocks made up? Mention the predominant materials of rocks. Mention some of the rocks usually described as *igneous*, and some of those called *metamorphic*.

6.—Mention the principal divisions of stratified rocks, and the British subdivisions of the middle part of the middle period.

7.—What are *fossils*, and what is their use in Geology?

8.—Explain the mode in which water is obtained — 1. from land springs, and 2. from Artesian borings.

9.—What Minerals are chiefly obtained by mining operations from beds, and what from mineral veins? Explain the process of *shoding*.

APPENDIX II.

GENERAL OUTLINE OF THE GEOLOGY OF INDIA.

The whole peninsula of India is a great triangular promontory, terminated in the north by the Himalayan chain, and on the east and west by the sea. It is connected geologically and physically with Asia Minor by Beloochistan and southern Persia; and on the east it joins the northern extremity of the Burman Empire by the province of Assam.

India is crossed by the Himalayan range, which forms the northern boundary of the peninsula. It is also crossed by the Vindhya range, another east and west chain placed in north latitude between 22° and 23°. Between these two ranges is the valley of the Ganges, running towards the east; and south of the Vindhya range is the valley of the Nerbudda, which runs towards the west. Besides these principal ranges there is the great range of the Western Ghauts, forming a north and south chain on the Malabar coast, and the less important range of the Eastern Ghauts on the Coromandel coast, the latter being only separated from the Northern Circars by the valleys of the Kistna and the Godavery. A number of less important secondary ranges extend in various directions through the country, and there are also considerable tracts occupied by lofty table-land.

India may thus be considered as divided into three portions, each distinct from the others. The northernmost of these extends southwards from the great Himalayan chain, and includes the whole valley of the Ganges; the central includes the valley of the Nerbudda, the province of Malwa and the adjoining provinces; and the southernmost extends from about the twentieth degree north latitude to Cape Comorin.

The grand feature of Indian Geology is the prevalence of crystalline and metamorphic rocks. These appear partly forced up through the regularly deposited strata, and partly covering them up by broad sheets that have been poured out in a melted state. They include granite and many porphyries, and enormous masses of basalt. Besides these are metamorphic rocks in yet greater profusion, gneiss and mica schist, the former especially, occupying very extensive tracts.

The rocks and fossils of the Palæozoic period would seem nearly confined to the northern half of the peninsula. Secondary rocks have been observed at Cutch, and near Pondicherry, and possibly also exist in various other parts of the country. Their true position and age have only been made out in the two districts mentioned.

Tertiary rocks abound in India and are probably of various periods, though many certainly come down to very recent date. The most remarkable localities for Tertiary fossils at present known are in the Sewalik range and in the Gulf of Cambay. The vast deposits called regur (the cotton soil of India), kunkur, and laterite, cover a very large part of the district not occupied by the igneous and metamorphic rocks. The great valleys of India are covered with extensive and thick masses of alluvial detritus.

COAL DISTRICTS IN NORTHERN AND CENTRAL INDIA.

The coal of India hitherto described is chiefly obtained from the northern and central portions of the peninsula.

The Himalayan range, which forms a perfect barrier, continuous with greater or less regularity, separating India from Northern Asia, is itself chiefly composed of gneissose rocks, highly crystalline, and penetrated by numerous veins of granite. On the south flanks of the principal chain there may be traced a well-defined sub-range of mountains, rising often to a considerable height, and in the western part distinguished by the name of the Sewalik range. These are of tertiary origin, and composed of hard sandstones, extremely fossiliferous (§ 755—758). Then succeed the great plains of India, the vast alluvial district through which the Ganges runs, and which near the mouths of that river spread out to an enormous area, receiving also the waters of the Burhampooter, and forming the joint delta—one of the most remarkable in the world—on which Calcutta and a multitude of important towns are placed.

On the right or south bank of the Ganges, and on the left (also the south) bank of the Burhampooter, the granitic and gneissose rocks which are covered up to a considerable distance by the alluvial mud of the two great rivers reappear. They form the range of the Garrow and Caissar mountains, commencing near Silhet and extending eastwards, and by a number of inferior ranges running at last into the Vindhya range and passing towards the west.

It appears to be chiefly in hollows or basin-shaped depressions in these granitic rocks that the coal of northern and central India exists.

Before proceeding to give an account of the various districts that have been described as presenting coal, it may be as well first to allude to the rocks ordinarily associated with it.

These are limestones, often poor and argillaceous; sandstones of various kinds; clayey and shaly beds, and bands of ironstone. The coal is in layers of various thickness, sometimes very considerable, but more frequently poor and unequal.

The limestone is said generally to underlie the coal; but its thickness is not known nor are there any clear and distinct accounts by which it can be identified. It is barren of fossils for the most part, but certainly not always, and careful investigation might discover some specimens which would be useful in determining its age, and identifying distant beds.

The coal and shale appear to be associated much as in the other coal-districts, and there can be no doubt that the shale contains fossils. It is of the greatest importance that these should be forwarded to England for examination and comparison.

The shale appears to become gritty in its upper members and passes into a gritty micaceous brownish-grey sandstone, sometimes becoming flaggy. This sandstone is said to form the surface rock generally in the coal-districts, and to be presented in low round-topped hills and undulated ground.

The coal that has been found of the greatest value in point of quality in India is considered to be that lowest in position; and the varieties occurring east of Bengal in Assam is said to be better than that met with in the western district. The Silhet and Nerbudda are accounted the best of all, and according to present appearances will prove the most available and lasting sources of supply.

The coal-districts of India may be considered as five in number,—three in Northern India and one in Cutch, while the fifth includes the province of Arracan and the coast of the Burman Empire near Tenasserim. Of these the Cutch coal is certainly not of the carboniferous epoch, and it appears to be of little importance at present and unpromising.

The whole district, extending from the neighbourhood of Hoosungabad on the Nerbudda river (lat. 23° N. long. 78° E.), on the left or south bank of the river, and extending in a north-easterly direction for a distance of about 400 miles to Palamow, thence eastward for 250 miles to Burdwan, near Calcutta, and running northward for 150 miles to Rajmahal, exhibits, it would appear, at intervals by no means distant, a continually repeated outcrop of rocks, consisting of sandstones and shales, with occasional limestone. Throughout this wide tract a number of beds of coal have been recognised, of variable thickness and value, but all appearing to exhibit evidence of the existence there of a great coal-district.

On the flanks of the Garrow Mountains near the Burhampooter, and on both banks of that vast river, we find another, perhaps a continued outcrop of similar beds, also containing coal, and reaching in

a north-easterly direction for nearly 400 miles. The intermediate plains, whose breadth between Rajmahal and Jumalpore is about 100 miles, are chiefly alluvial, and thus it is possible that there exists a vast range of carboniferous strata, reaching for upwards of 1000 miles along the flanks of the Himalaya mountains,—the distance from the mountain chain gradually increasing as we advance westward, the mountains trending northwards and the outcrop of the carboniferous bed southwards, until finally, the distance between them being upwards of 500 miles, the relation is not easily recognised.

I. Commencing with the neighbourhood of Calcutta, we have first to consider the Burdwan coal-district, with which may be grouped the Adji and the Rajmahal fields, all these being on the banks of either the Hooghley or Ganges, or on the tributaries of these rivers. The Burdwan district has been long known, and a good deal worked. The workable beds of coal are nine and seven feet thick respectively. They are associated with sandstone, shale, and a little clay-ironstone, and about six other thinner seams of coal, while other thick beds are mentioned, but their real existence as separate beds is doubtful. (See § 943.) There are thirteen spots at which this coal is mined, but most of them are surface workings. The deepest sinking is 190 feet. The distance to Calcutta is about 90 miles, but the actual transit of coal is nearly 200 miles. There would seem to be a continuous outcrop of the same kind of rocks from Burdwan up the Adji river, and northwards to Rajmahal. On the Adji river the coal has been worked in more than one spot, and is found to be of about the same quality as that of Burdwan ; but neither of them is considered of nearly so good quality as the English coal. Further on, at Rajmahal, coal is known to exist, but has not yet been much worked. The quality of that which has been obtained does not appear good.

II. The Burdwan coal-field appears to be directly connected with a district at Palamow, in which coal has been worked in no fewer than four places. The coal here apparently reposes in a valley enclosed by hills of granite, and is associated with a good deal of iron. There are several beds that are of workable size, but a good deal of the coal is heavy and of inferior quality, and some of it appears to be anthracitic. These coal-beds are not far from the Soane river, and about 100 miles from its confluence with the Ganges a little above Dinapoor and Patna ; but the Soane is not at present navigable. To the west of Palamow the carboniferous beds are described as appearing along two irregular lines, the one towards the southwest for 150 miles, reaching beyond Koorbah, and the other more westward, by Sohagepoor, to the Nerbudda. These beds appear to connect themselves with the Burdwan coal-field ; and near Ramurgh coal has been obtained in two or three places. This coal is said to

be of very good quality, and the seam is of very considerable thickness. Westwards, again, from Palamow, and at a distance of about 50 miles, coal has been found in several places in Singrowli, but the beds at present known are thin; and again, to the south-west, the same mineral occurs at Sirgoojah, where fine coal has been seen, but is not used at present. Between the Singrowli coal and Jubbulpore excellent coal has been found in several places, indicating an extensive coal-field; but the nature and thickness of the beds are not stated.

The Nerbudda district, although from the drainage of the country it belongs to the Bombay side of India, is manifestly more related, so far as the old rocks are concerned, to the Bengal territory. The coal is about 350 miles from Bombay, and the Nerbudda river is at present not navigable. There seem to be three districts in the Nerbudda valley in which coal is found, but the most important of them is that near Gurrawarra, about midway between Hoosungabad and Jubbulpore. The coal here, indeed, appears to be perhaps the best hitherto found in India, and exists in beds three in number, whose thickness respectively is said to be 20 feet, 40 feet, and 25½ feet. There are also other beds, one of which is four feet.

The discovery of this, the Benar coal-field, promises to be of great importance. It is also very near another basin, where there are beds also of excellent quality, one of them six feet in thickness. At Jubbulpore itself coal has been found at a depth of 70 feet, one bed being nearly twelve feet thick.

III. Let us consider now the district east of Calcutta. We there find true carboniferous rocks on both flanks of the Garrow mountains, commencing near Jumalpore, and thence continuing north-eastwards, for a distance amounting on the whole to nearly 400 miles, through Lower and Upper Assam. The district nearest Calcutta is Silhet, on the south flanks of the Garrow, where eleven beds of coal have been determined, whose total thickness as already ascertained amounts to 85 feet. This coal is of excellent quality, and can as readily be conveyed to the Upper Ganges as the Burdwan coal. The most remarkable beds occur at Cherra Ponji; but these appear irregular, although they are undoubtedly of great thickness in several spots, amounting sometimes to nearly 30 feet. There are also other important beds. They have been known for more than ten years, but have not been worked; and since their first discovery large quantities of iron have been smelted with charcoal.

After passing the districts in which the coal has been thus clearly exhibited, we proceed next to the Assam districts, also more or less continuous, and extending for about 350 miles chiefly along the south side of the Burhampooter; the whole being divided into the two groups of Lower and Upper Assam, separated at Bishenath, 170 miles

above Calcutta. Six coal-fields are enumerated in the Upper district, and three in the Lower; but the latter, although it would seem not so promising, are looked on as scarcely less important in consequence of their greater accessibility.

So far as details are concerned, the Lower Assam coal offers little positive information; the indications consisting rather of rolled fragments drifted, than of distinct and well-marked beds. It is called lignite in a report from Lieut. Vetch; but both coal and lignite are terms frequently used without reference to any peculiar character of the mineral, or any geological position. Similar beds of coal or lignite to those found in Lower Assam, south of the Burhampooter, are also mentioned as occurring on the north in three of the streams flowing into that river from the Bootan range. The Upper Assam coal is manifestly of great interest, and likely to prove very important. It is associated with abundance of clay ironstone.

About 80 miles above Bishenath, other beds, stated to be 6 feet thick, have been worked for the sake of trying the economic value of the coal. It is described by the commander of one of the Assam Company's steamers, in a letter dated 24th January, 1845, as far the best he ever had on board a steamer, and far superior to any coal in Calcutta. From the growing importance of the tea-trade from Assam, this is likely, therefore, to be of great value. Still further up the country there are several important beds, dipping, it would appear, at so high an angle, and placed so unfavourably with regard to present means of transport, that it would be difficult to work them. The other beds that appear in this district are exposed to the same difficulty; and the coal throughout Northern India appears to be in this respect unfavourably placed.

Passing on now to the other districts in India and the East, in which carboniferous rocks and beds of coal have been met with, we have to consider two, the Tennaserim and the Arracan districts, which, from their vicinity to India and their geographical position, are of very marked importance. The former has been known for some years, and there are said to be four localities at which coal appears; but of these only one seems likely to prove of economic value. From the accounts given of this coal there is every reason to conclude, that one of the beds is not of the carboniferous period; and although another (on the Thian Khan) has been the subject of a far more favourable report, being called cannel coal, and stated by Mr. Prinsep to be an admirable coal for gas, there is yet much probability of the whole being of the tertiary period. These beds have been described in the "Journal of the Asiatic Society" for 1838.

In Arracan there are 11 beds of coal, but all of them are thin, and their position nearly vertical. They are said to be associated with sandstones, limestones, and shales; but it is clear that they can at

present be looked at only as indications, and not of any practical importance.

Such is a general account of the coal-districts of India, so far as evidence can be obtained from the report of the committee for the investigation of the coal and mineral resources of India for May, 1845.

The true age of these beds is a matter of great interest, but unfortunately the evidence is imperfect in a most important point. The beds of coal, occurring chiefly in granitic basins, and often detached, may be, and some of them most likely are, of the Devonian or Carboniferous age; they may, however, be Oolitic, like the imperfect coal of Cutch and of some parts of our own country, or they may be tertiary lignites. Now it may seem of little importance to the mere surveyor what the geological position of these beds may be, provided there is the material he needs; but experience renders it probable that on the mere question of age does, in fact, depend much of their true economic value. Could it be satisfactorily shown that throughout the wide district of Northern India there is a true outcrop of carboniferous beds — such as occur in England, in America, and even in Eastern Australia—the value of a very large part of the possessions of England in the East might be considered much increased; for if the beds should prove steady and permanent, the application of the resources in knowledge and wealth of a rich and an enterprising people, would very soon bring into operation, in all those districts, manufactures and commerce on the grandest scale. The navigation of the rivers, the state of the roads, the means of communication by railroads, would be immediately established or permanently improved; and the result must be improvement in the condition of the country.

The result of the inquiry already made being incomplete, it must be considered unsatisfactory, though no doubt highly suggestive for future investigation. Little value can be attached to mere statements of the existence of carbonaceous matter in beds, because many of the important practical conditions are independent of the appearance and experiments on detached fragments, and are learned only when such an amount of detail is given with regard to the geological conditions under which the coal appears, that we may fairly judge of the probable extent of the deposit.

A series of observations, then, connecting any of these apparently detached deposits by uniformity of association, or still more by an identity in the species of fossils obtained from them, would be of the greatest practical benefit, and would assist in enabling us to form sound conclusions with regard to their value. To make such observations should be the object of every one who has the opportunity of travelling across Northern India. It will be long before a matter which involves so much detailed personal investigation, and the

grouping together of so many facts, is fully accomplished; but meanwhile every accurate observation of dip and strike; every section across a district; every map, however rough, of one of the detached basins; every specimen of fossil which will give only a few leaves of ferns or characteristic portions of a shell, will be a step in advance, and will bring us nearer the time when we shall have a clear and distinct idea of the true mineral riches in India in this important respect.

Table showing the position and quality of the most important Coal-fields of India.

Province.	District.	Beds.	Quality.	Analysis. Vol. mat.	Carbon.	Earthy matter.
1. Bengal....	Burdwan ..	Several, 9 & 7 ft.	Good..........	36	60	4
	Adji-river..	6 to $13\frac{1}{2}$ feet.	Like Burdwan ..			
	Rajmahal ..	Not worked.				
2. Lower Assam	Kurribari ..	Not traced	Brown coal ..	50 70	40·6 25·4	9·4 4·6
3. Silhet	Garrow-hills	Undefined	Excellent	34	65·4	1·5
	Cherra Ponji	Several, 2 to 28 ft.	Slaty..........	36	41·0	23·0
4. Upper Assam	Namsong ..	6 feet	Very good.			
	Suffry	Up to 12 yards..				
	Boorhath ..	6 to 8 feet	Caking coal	45	52·7	2·3
	Jeypore ..	2 to 9 feet......	Superior	48	46·2	5·8
	Namroop ..	Up to 20 feet.				
	Kosiah hills	Undescribed....	Very few ashes	38·5	60·7	0·8
5. Behar	Palamow ..	Several beds to 6 feet......	Slate coal .... Slaty crop .... Ditto ditto....	44 32 25	50 58 63	6 10 12
6. Central districts ..	Ramgurh ..	3 feet	Promising....	31 27	53 61	16 12
	Ruttenpore	Immense thickness				
	Surgooja ..	Many yards....	Fine			
	Singrowlie	Thin..........	Middling	54	32·2	13·8
	Sohajepore	Not described.				
7. Nerbudda Valley ..	Gurrawarra	Up to 40 feet.	Excellent			
	Shawpore ..	2 to 6 feet.				
	Jubbulpore	Undescribed....	Excellent	50	47·1	29
8. Tenasserim.	Mergue....	About 6 feet....	Caking	55	40	5
9. Arracan....	Ramree....	Thin seams	Caking coal	36	49	15
	Cheduba	Thin seams ..	Inferior Cannel coal	46·8	41·2	12
10. Guzerat....	Cutch	Many thin seams.				
11. Borneo		Several beds	Doubtful			
	Labuan ..	Several beds up to 12 feet ..	Good..........			

In the following Notes some information is given of the more remarkable facts with regard to each district.

1. *Burdwan Coal.*—Although this coal-field has been known for thirty years there is yet much to be learned, not merely of its relation with other neighbouring coal-fields, but even of the geological age of the coal and associated beds, and the probable extent and value of the deposit.

As many as thirteen collieries are described as having been undertaken. The supply seems increasing. It seems however quite clear that without railway communication there will always be difficulties and expenses in the transit, greatly interfering with the development of the mineral wealth of this district, whatever it may be. The association of the beds here does not seem to differ greatly from that in the Assam districts, but as the sinkings are deeper there is greater regularity and uniformity in the arrangement.

Adji River.—An extensive area on both sides the banks of this river is occupied by the coal-field. It is not quite equal to the Burdwan, but is more readily available. It requires careful working out to connect it with the adjacent similar deposits.

Rajmahal. — The coal hitherto obtained and experimented on from these mines is considered very inferior in quality.

2. *Kurribari.*—The brown coal here is apparently in small basins; it is of inferior value, and its thickness is not considerable. It must not be confounded with the bituminous coal in the neighbourhood. There seems to be a considerable quantity of drifted coal in the rivers, and the tracing of this to its source might perhaps lead to useful results.

3. *Silhet.*—This coal is described as being of excellent quality and is even better situated for supplying some parts of the Ganges than the Burdwan field. By far the most remarkable of the different localities in this province is that of Cherra Ponji, situated on a tableland composed of horizontal beds of sandstone rising abruptly from 3000 to 4000 feet above the plains of Silhet. The beds of coal are seen in precipices thirty or forty feet high, consisting of coal, limestone and shale. The thickness of the coal is very variable, from two feet eight inches to twenty-eight feet. The lowest bed described is a compact dark bluish or blackish-grey limestone, containing fossils; this is covered by a few thin beds of dull dark-coloured gritty limestone, which are succeeded by thin beds of sandstone, and these by beds of blackish shale, upon which the coal reposes. Above the coal are usually a few beds of soft sandstone, loose sharp sand, and clay. These rocks are considered to be the lower beds of the coal formation. Specimens of the fossils from the limestone would be of great interest.

The manufacture of iron is carried on in the neighbourhood to great extent, but charcoal alone is used as fuel.

It appears not unlikely that the Cherra beds of coal are very local in every respect. The quality of the coal is said to be excellent.

4. *Upper Assam.*—On the Suffry, at one spot, the dip is described as about 40°. Limestone probably underlies the coal; the upper bed of coal is six feet high (thick?), with clay roof. The quality of this coal is said to be excellent; the thickness is certainly considerable and the beds seem workable, but at present communication with Calcutta is difficult. Abundance of clay ironstone is found with the coal. The coal has been tried in steamers.

5. *Behar.*—The valley of Palamow in this province contains important beds of coal, but they are not at present readily available for want of means of communication. The quality is described as good and bituminous. The coal occurs in shale and sandstone with ironstone and is in the immediate neighbourhood of granite. Fossils occur in the shales, but they are not described.

These beds promise to be of great importance, being situated in very favourable lines of communication. The coal also is of good quality, and the habits of the people favourable to its use.

6. *Ramgurh.*—The beds are of moderate thickness, and the coal resembles that of Burdwan.

Ruttenpore.—The thickness of the coal here is described as amounting to 200 yards. It is laid open by the side of the river Hutsoo. There is no evidence to show how far this account, deduced from a sketch by Col. Ouseley, may be correct. The quality of the coal is described as good, and the beds associated include a black marble. It would be interesting to obtain further information concerning this bed, which is situated not far from the sources of the Nerbudda.

Surgooja.—The coal here is simply described as of good quality and abundant. There are two localities named, one of them on the Rehar river, said to be easily accessible.

Singrowlie.—This locality is on the table-land at the head of the Soane, 50 miles west of Palamow. There are several beds; most of them, as at present described, appear to be very thin.

Sohajepore.—This is between Singrowlie and Jubbulpore, and conducts us to the Nerbudda fields. There are several places referred to as exhibiting coal and associated shales and ironstone, but there is much uncertainty in the accounts.

7. This district (the Nerbudda Valley) is of great importance, since the supply for Bombay must be derived hence. It is of the greatest importance that the true value of the coal-fields should be clearly and distinctly made out.

Gurrawarra.—Seventy miles above Hoosungabad. This is said to be the most important coal in the district, and even, according to Col. Ouseley, in India. Occurring near Benar, it may be called the Benar coal-field. On the Seeta Rewar river there appear to be three beds,

whose thickness is 20, 40 and $25\frac{1}{2}$ feet respectively; these are covered with a thin bed of sandstone, and repose on and amongst quartz sandstones. The important inquiry in this case would be the probable extent of the bed. The quality is said to be superior to imported Scotch coal. There is limestone and iron in the neighbourhood.

As this spot is in the line of one of the projected railways, it becomes of very great importance that its true value should be determined as speedily and as certainly as possible. At present there appears to be no information with regard to the dip or the probable superficial limits of the outcrop.

Shawpore.—This is the Baitool district, and is situated at Hoosungabad, 30 or 40 miles from the Nerbudda, without convenient means of transport; the beds are said to be numerous, extensive and near the surface. No account is given of limestone.

Jubbulpore.—There is said to be much very excellent coal from this neighbourhood. At nine miles from the station there is a large bed of first-rate quality, many yards thick, crossing the bed of the Soane; and in the station itself, at the depth of 70 feet, coal is also met with.

8. There are four coal-fields in the Tenasserim provinces. The quality in one appears anthracitic, in another highly bituminous. Considerable expense has been incurred in this district, but apparently without any favourable result.

9. There are many indications of coal in Arracan, but the beds are all so nearly vertical that it seems unlikely they can be worked with profit. They are associated with limestones, sandstones, and shales, and are considered very good in point of quality. The limestones are fossiliferous, but the fossils are not described.

10. The two thin seams of coal at Bhooj in Cutch belong to the Oolitic period. They have been worked at considerable cost, but do not promise much chance of success.

11. The island of Borneo appears to contain very extensive and valuable deposits of coal coming out to the surface near some parts of the coast. The small island of Labuan, near Borneo, also presents very large and valuable resources, several seams of coal having been described highly inclined and disturbed, but of tolerably good quality. The following analysis of specimens forwarded to the Admiralty is taken from the anniversary address of Sir H. T. de la Beche, to the Geological Society, in 1848. The specimens were obtained from the crop of the bed, and are, probably, not equal in quality to the mass. The Labuan coal is from a nine foot bed, which has been traced four miles and a half in a WSW. direction, dipping about 24° to SSE., and reposes on a clay-bed. The Kiangi specimens were from the main land of Borneo. An ample supply appears to be obtainable from either locality.

	Labuan.	Kiangi. 11 ft. bed.	Kiangi. 3 ft. bed.
Carbon	64·52	70·30	54·31
Oxygen	20·75	20·38	25·23
Hydrogen	4·74	5·41	5·03
Nitrogen	0·80	0·67	0·98
Sulphur	1·45		
Ash	7·74	3·24	14·45

ACCOUNT OF THE GEOLOGY OF SOUTHERN INDIA.

This part of the peninsula presents two mountain ranges, known as the Eastern and Western Ghauts, and the intervening table-lands have an elevation varying from 500 to 3,000 feet above the sea. A tract varying from one to seventy miles in breadth extends at the foot of these ghauts between the hills and the sea. The mean elevation of the Western Ghauts is about 4,000 feet, and of the Eastern, 1,500 feet.

Almost the whole of Southern India is occupied by crystalline and metamorphic rocks, the latter constituting by far the larger part. They are for the most part schistose beds penetrated and broken up by crystalline masses, and are partially capped and fringed on the Western side by laterite, and on the Eastern by sandstone, limestone, and laterite. The sequence of metamorphic rocks is not invariable, but gneiss is described as usually lowest, and next to it occur mica and hornblende schists, actinolite, chlorite, talcose and argillaceous schist and crystalline limestone. The strata are often violently contorted, and not inclined with any regular dip.

The beds overlying the metamorphic rocks consist of various argillaceous, arenaceous and siliceous schists, in which no fossils have yet been found, and whose age is uncertain. The limestones are considered to be generally lowest, and after them come calcareous shales, argillaceous shales and slates, and then sandstones and conglomerates, the latter containing diamonds. This diamond rock is considered by Capt. Newbold as of Palæozoic age, and certainly appears very ancient. An account of the working of diamonds from diamond gravel, is inserted in a previous chapter (§ 775). The diamond sandstone is described as not very dissimilar to some Devonian rocks of England.*

The only Secondary deposits in Southern India appear to be the lower cretaceous fossiliferous limestones of Pondicherry and Trichinopoly: these have been already alluded to.

The Tertiaries of this district, of most importance, are those called *laterite, regur*, and *kunkur*. The latter two have been described, but the laterite now requires notice.

* See Summary of the Geology of Southern India. Journal of the Royal Asiatic Society, vols. viii. ix. and xii.

Laterite varies much in colour and composition, but generally presents a reddish brown or brick-coloured cellular clay, more or less indurated and used by the natives as bricks when cut square, whence its name *Laterites*, or brick-stone. It often passes into a hard compact jaspideous rock on the one hand, or into loosely aggregated grits or sandstones on the other. It is also, sometimes, a red or yellow ochre or lithomarge, and occasionally becomes a conglomerate containing fragments of quartz and crystalline rock embedded in ferruginous clay. The cavities or cells are occasionally empty, but sometimes filled by various substances. The iron prevails to such an extent as to constitute some portions of a true ore of that metal. It hardens greatly and permanently on exposure, and is well adapted for buildings and fortifications. Many extensive caverns occur in the rock. Laterite has been supposed to be weathered igneous rock, but this is not probable: it is, however, of aqueous origin, and of older date than the regur and kunkur which it underlies.

The crystalline rocks of Southern India are considered by Capt. Newbold to be of several ages, and there are, at least, three distinct varieties, consisting of granites, basaltic greenstone, and overlying traps or recent basalt. The granites include two principal varieties, dykes of the one intersecting the other. The basaltic greenstone penetrates all rocks older than the laterite, and the overlying trap or basalt, which is yet more modern, covers a vast extent of surface, and conceals a large amount of rocks of different origin.

The following scheme of the stratified rocks of Southern India, taken from Capt. Newbold's paper in the Journal of the Asiatic Society, already quoted, will properly conclude this notice. The views may possibly admit of modification in some matters of nomenclature.

TERTIARY ROCKS.	CORRESPONDING EUROPEAN PERIODS.
1. Sandstone of Coromandel, and Paumbum, and Cape Comorin, with recent sea-shells.	Recent.
2. Coromandel black clay, underlying Madras. *Regur*. 3. Ancient *Kunkur* and gravel, with remains of Mastodon.	Newer Tertiary.
4. Silicified wood-deposit of Pondicherry, and older *Laterite*	Middle Tertiary.
5. Freshwater limestone of Nirmul, Hydrabad, and Rajahmundry	Older Tertiary.
SECONDARY ROCKS.	
6. Limestone beds of Trichinopoly, Verdachellum, and Pondicherry	Lower Cretaceous.
PALÆOZOIC ROCKS.	
7. Diamond sandstone 8. Limestone 9. Lower diamond sandstone	Carboniferous, or Devonian.

GLOSSARY OF SCIENTIFIC TERMS.

ABRASION. The removal of particles by rubbing.

ABSORBENT. Capable of sucking up fluids. Thus chalk is said to be *absorbent* of water.

ACCLIMATIZE. To accustom to a climate different from that which is natural:—applied both to plants and animals.

ACCRETION. Increase of size or growth by the mechanical addition of new particles.

ACICULAR. Needle-shaped.

ACIDULOUS. Slightly acid.

ACLINIC LINE. The magnetic equator. See § 31.

ADHESION. See § 18.

ADIT. The name given in mining to an underground horizontal gallery or tunnel used in carrying water out of a mine to the lowest convenient level (§ 1151).

AEROLITES. Stones which appear to have fallen from the higher parts of the atmosphere. They are sometimes called Meteorites. See § 449.

AFFINITY (in Chemistry). The tendency of various substances to combine. See § 21.

AFFINITY (in Zoology and Botany). The condition of similarity in essential characters, and not merely by similarity of form or use, as in analogy.

AFTER-DAMP. The gas (carbonic acid gas) produced in mines after an explosion of fire-damp.

AIGUILLE (a needle). Used in Physical Geography to designate the peaks of mountains.

ALBUM-GRÆCUM. The name given to the calcareous excrement of some of the carnivora.

ALGÆ. A division of plants including the common sea-weeds.

ALKALI (in Chemistry). That which in combination with an acid produces a neutral salt.

ALLOTROPY. See § 291.

ALLUVIUM. Earth, sand, gravel, stones, and other substances transported by water, and not permanently buried beneath the waters of lakes and seas. The adjective *alluvial* is often used. *Alluvion* is a synonym.

ALUMINOUS. Containing alumina, or rather silicate of alumina, which is the base of pure clay. Thus, aluminous means *clayey*. The word is, however, sometimes used in the sense of containing *alum*, a sulphate of alumina and potash.

ALVEOLUS. Literally a socket, or small cavity or cell. Used in Palæontology to signify the chamber of a belemnite.

AMALGAM. A compound of any metal with mercury.

AMMONITE. A fossil genus of many-chambered shells allied to the Nautilus, named from their resemblance to the horns on the statues of Jupiter Ammon.

AMORPHOUS. Without regular form.

AMORPHOZOA. Animals without definite form—sponges.

AMYGDALOID. Almond-shaped. Any rock is called by this name which contains rounded or elongated minerals embedded in some simple mineral or base.

ANALOGY. A relation of resemblance as distinguished from that of affinity. See *Affinity.* An *analogue* is a body that corresponds with and represents another, as a fossil species frequently does a recent one.

ANALYSIS (in Chemistry). The separation of a substance into its component elements.

ANEMOMETER. An instrument for measuring the force and velocity of the wind.

ANGLE. The inclination of two lines, or more than two planes, meeting at a point; or the inclination between two planes. See *Solid angle.*

ANHYDROUS. Without water. Simple minerals, not containing water as an ingredient, are called anhydrous.

ANIMALCULES. The name given in Zoology to exceedingly small animals which cannot be studied without the assistance of the microscope.

ANOMALY. An exception to a law.

ANOPLOTHERIUM. The name given to a characteristic genus of a group of extinct quadrupeds found fossil in the older Tertiary deposits, and nearly allied to the tapir and pig. The Palæotherium is another genus also characteristic and nearly allied.

ANTAGONIST FORCES. Two powers in nature, one counteracting the other and preserving a general equilibrium in appearance on the earth's surface.

ANTARCTIC. Opposite the Arctic. The name given to the southern as distinguished from the northern or arctic region of the earth.

ANTEDILUVIAN. Before the deluge — a term generally employed in reference to periods of great but indefinite antiquity.

ANTHRACITE. A kind of coal. See § 353.

ANTICLINAL. Or *Anticlinal axis.* A saddle-shaped position of rocks, the result of disturbance. See § 610.

ANTIPODES. The inhabitants of that district of the earth diametrically opposite to the one in which the person using the term may happen to be at the time or may refer to.

AQUA-FORTIS. Nitric acid.

AQUA-REGIA. A mixture of nitric and muriatic acids capable of dissolving gold.

AQUEOUS. That which is dependent on water. Aqueous rocks are those produced by deposit from water.

ARCHIPELAGO (in Geography). An important sea containing numerous islands.

ARCTIC. Northern. Thus we speak of the Arctic circle, the Arctic pole, &c.

AREA. A space. Any limited district is sometimes called an area.

ARENACEOUS. Sandy.

ARGENTIFEROUS. Containing silver.

ARGILLACEOUS. Clayey.

ARTESIAN SPRINGS AND WELLS. See § 1049.

ARTICULATA. A natural division of animals, having their limbs articulated or jointed together, like the lobster.

ASHLER. The name given to freestone when squared for building purposes.

ASSAY. The determination of the quantity of a metal contained in a metalliferous ore.

ATMOSPHERE. The whole body of the air floating above the solid and fluid matter on the earth.

ATOLL. A coral island of a ring-shape, consisting of a circular strip of coral surrounding a central lake of salt water.

ATOM. The name given to the ideal ultimate particles of elementary bodies.

ATTRACTION. The force which tends to bring one mass of matter in contact with another. See § 16.

AURIFEROUS. Containing gold.

AURORA. An appearance of light in the heavens, probably connected with the disturbance of magnetic equilibrium. When proceeding from the neighbourhood of the North Pole it is called *aurora borealis*, when from the south, the *aurora australis*.

AVALANCHE. A mass of snow detached from great heights in many lofty mountain districts, and falling into valleys below, causing great destruction.

AXIS. See *Anticlinal* and *Synclinal Axis.*

AZOTE. Nitrogen gas.

BACULITE. A straight, many-chambered shell, somewhat resembling an ammonite unwound.

BAROMETER. An instrument for measuring the weight or pressure of the air by comparing it with that of a column of mercury or water. The *Aneroid barometer* is a modification. See § 87.

BARRIER-REEF. A reef or bank of coral parallel and forming a barrier to an island or coast-line, and at some distance from the coast.

BASALT. An igneous rock, often columnar and supposed to be ancient volcanic lava. It is the most common of the group called *Trap-rocks.*

BASIN (in Physical Geography). An area of drainage including the whole space drained by a river and all its tributaries.

BASIN (in Geology). The name applied when deposits lie in a hollow or trough, like the bed of a lake.

BASSETT. See *Outcrop* of strata.

BEACH. The shore of the sea.

BED OF STRATUM. A layer of material the whole of which exhibits some common character. A bed may or may not exhibit stratification or lamination.

BELEMNITE. A dart-shaped shell, probably the ancient representative of some of our cuttle-fish. The shell is conical and chambered.

BEVELMENT (in Crystallography). See § 253.

BIND. The name given in mining to argillaceous or clayey shale. It is a bed often associated with coal.

BLUFF. A high bank presenting a precipitous front to the sea or a river.

BOTRYOÏDAL (in Mineralogy). Clustered like a bunch of grapes.

BOULDERS. Large rounded or angular blocks of stone, unlike the underlying rocks, embedded in loose soil or gravel, and brought from a distance.

BRACHIOPODA. A group of shell-bearing animals having two long spiral arms serving to assist in locomotion and for other purposes.

BRECCIA. A rock made up of angular fragments of various materials cemented together by lime or other substance.

BROWN-COAL. Tertiary coal or lignite only partially mineralised.

BUFONITE. A name sometimes given to the teeth and palatal bones of some fishes found fossil.

BUHR-STONE. A siliceous rock full of cavities, found in America, and used as a mill-stone. Sometimes spelt *Burr-stone.*

BYSSUS. A tuft of hairs or beard attached to certain bivalve shells, and fastening the animal to a rock.

CAIRNGORUM. A variety of quartz crystal.

CALAMINE. The common ore of zinc.

CALAMITE. A fossil from the coal-measures resembling a gigantic reed (*calamos*).

CALC SINTER. The calcareous deposit from springs holding carbonate of lime in solution.

CALCAIRE GROSSIER. A coarse limestone of the Older Tertiary period, found in the Paris basin.

CALCAIRE SILICEUX. A compact siliceous limestone sometimes replacing the calcaire grossier.

CALCAREOUS. Containing lime.

CALCINE. To burn to a calx or friable earthy residuum.

CALP. An impure limestone belonging to the Carboniferous and Devonian series.

CAMBRIAN. Belonging to Wales. The "Cambrian system" in Geology, is a name suggested by Professor Sedgwick, to designate part of the Silurian series of North Wales.

CANNEL COAL. A compact clean coal burning freely like a candle. It greatly resembles jet.

CAPILLARY. Hair-like.

CARAPACE. The upper shell of reptiles.

CARBONIFEROUS. Containing carbon. The "Carboniferous system" in Geology is that which contains the coal-measures and the carboniferous or mountain limestone.

CARNIVOROUS. Flesh-eating. The "Carnivora" in Zoology consist of a group of animals eminently carnivorous.

CATARACT. A waterfall.

CAUDAL. Connected with the tail.

CEMENT. The matter by which two solids are made to adhere.

CEPHALOPODA. A group of animals of which the Nautilus and Cuttle-fish are examples, having the locomotive apparatus immediate over the head and stomach.

CETACEANS. The whale tribe.

CHALYBEATE. Water holding iron in solution.

CHAMBERED. The term applied to those shells regularly divided by natural equidistant partitions. Many-chambered or *multilocular* is a name given to the group of shells inhabited by the cephalopoda.

CHERT. A siliceous mineral, resembling common flint, but of coarser texture.

CHOKE-DAMP. The name given to the carbonic acid gas found in wells and mines.

CILIATED. Fringed with very short hair-like appendages.

CLAY. An impure, unctuous and tenacious earth.

CLEAVAGE (in Mineralogy). See § 249.

CLEAVAGE (in Geology). See § 597.

CLIMATE. See § 104.

CLINOMETER. An instrument for measuring the dip and determining the strike of beds or strata.

CLUNCH. The hard beds of the lower chalk.

COAL-MEASURES. The whole group of deposits, consisting chiefly of sands and shales, with which coal is usually found.

COBBLE. A pebble.

COHESION. A force of attraction acting only at very small distances, and when substances are apparently in actual contact. See § 18.

COLUMNAR. Arranged in columns.

COMBINATION, CHEMICAL. See § 19.

CONCHOIDAL. Resembling a shell. Used in Mineralogy to designate a particular kind of fracture. See § 305.

CONCHOLOGY. The study of shells.

CONFLUENCE. The point of junction where two streams meet.

CONFORMABLE. When the planes of bedding of two successive beds or strata are parallel to each other they are said to be *conformable;* when not parallel they are *unconformable*. See § 607.

CONGENERS. Species belonging to the same genus.

CONGLOMERATE or PUDDINGSTONE. A rock made up of rounded water-worn fragments of rock or pebbles cemented together by another mineral substance.

CONTEMPORANEOUS. Formed at the same time.

COOMBE. A hollow unwatered valley on the declivity of a hill.

COPROLITE. The fossil remains of excrement.

CORNU AMMONIS. See *Ammonite.*

COSMICAL. Relating to the universe.

COSMOGONY. The word formerly applied to speculations concerning the earth's age and history.

COSTEANING. A mining term. See § 1146.

COUNTER-CURRENT. A current running in an opposite direction to some other.

CRAG. The name given to certain Tertiary deposits in Norfolk and Suffolk. See § 735, 745.

CRAG AND TAIL. The condition of a hill, as of gravel, when one side is steep and the other a gradual slope.

CRANIUM. The skull.

CRATER. The cup-shaped cavity usually distinguishable at the summit of a volcano.

CREEP (in Mining). See § 1104.

CRETACEOUS. Belonging to the chalk. The "Cretaceous series" of rocks is that which includes the chalk.

CROPPING OUT. The *out-crop* of a bed is its first appearance at the surface.

CRUST OF THE EARTH. The external film of the earth exposed to view or in any way available for examination.

CRYSTAL. The regular form in which a mineral is presented when that form can be described mathematically. A mineral is said to be *crystalline* when its atoms are arranged with reference to some definite form.

CULM. An impure kind of coal. See § 930.

CUMBRIAN. Occurring in Cumberland. The "Cumbrian System" of Prof. Sedgwick is a part of the Silurian series of the Lake district of Cumberland and Westmoreland.

CURRENTS, MARINE. See § 122.

DEBACLE. A sudden rush of waters breaking down obstacles and removing detritus.

DEBRIS. The fragments of rocks removed by the action of weathering or by water.

DEFLECTION. Deviation from a straight course.

DEGRADATION. The wearing away of rocks, generally effected by aqueous action.

DELIQUESCENT. Becoming fluid by the attraction of water from the atmosphere.

DELTA. The alluvial land formed by a river at its mouth, usually expanded in a fan shape like the fourth letter of the Greek alphabet (Δ), and thence called *Delta*.

DENUDATION. The act of laying bare some rocks formerly covered up, the removal of the overlying masses being effected by water. See § 608.

DEPOSIT. Matter laid or thrown down.

DESICCATION. The act of drying up.

DETRITUS. Matter rubbed off by mechanical action from other rocks.

DIKE. See DYKE.

DILUVIUM. Accumulations of gravel and fragments of rocks removed from a distance, supposed by some to have been the result of a violent rush of water, but more probably left by icebergs that have melted on the spot.

DIMORPHISM. See § 291.

DIP (in Geology). The angle of inclination which the plane of a bed makes with the plane of the horizon.

DIP OF NEEDLE. The depression from horizontality of a magnetic needle not in the magnetic equator.

DISRUPTION OR DISLOCATION. A forcible rending asunder.

DOLOMITE. Crystalline carbonate of lime and magnesia.

DRUSE. A cavity in a mineral containing crystals.

DUNES. Low hills of blown sand.

DYKE. A rock, generally crystalline, occupying a rent or fissure in some other and older rock. A dyke differs from a mineral vein chiefly in its greater magnitude and in the absence of ramifications. The word is sometimes written *Dike*.

EARTH'S CRUST. See *Crust of the Earth.*

EARTHQUAKE. An undulation of the earth's crust. See § 195.

EFFLORESCENCE. The term used to describe the falling to powder of certain minerals on exposure.

EMBOUCHURE. The mouth of a great river.

EOCENE. The name given by Sir C. Lyell to the lowest and oldest division of the Tertiary series of rocks.

EPOCH. A fixed point in time from which a new period is measured. The term is also used to designate the period.

EQUATOR. An ideal great circle on the globe, everywhere equidistant from both the poles.

EQUIVALENT (Chemical). A number representing the relative weight of elementary substances, and used for them, as being equivalent to them. See § 10.

EROSION. The gradual wearing of an exposed rock as if by eating away.

ERRATIC BLOCKS. See *Boulders.*

ERUPTION (Volcanic). See § 218.

ESCARPMENT. The steep face of a mountain chain or a ridge of high land.

ESTUARY. An inlet of the land entered by the sea, but having a stream of fresh water coming in from the land.

EXOTIC. Foreign.

EXUVIÆ. A name sometimes given to all fossil remains found in the earth's crust.

FACE (in crystallography). The surface of a regular solid.

FALUN. A French provincial name for the strata found in the Touraine, corresponding to the Suffolk crag.

FAULT. The interruption of continuity of strata, accompanied by a displacement of one or both sides of the fissure (see § 615).

FAUNA. The whole group of animals peculiar to a country or natural region at some one period.

FERRUGINOUS. Irony, or containing iron.

FILAMENT. A thread or fibre.

FIORD, or FJORD. A deep narrow inlet.

FIRE-CLAY. A kind of clay not containing much alkaline earth, and therefore resisting fusion at high temperatures.

FIRE-DAMP. Light carburetted hydrogen gas evolved from coal in mines, and becoming explosive on mixture with common air (see § 1119).

FIRE-STONE. A stone that resists fusion at ordinary high temperatures. The Upper greensand deposits, between the lowest chalk and the Gault, are sometimes called by this name.

FISSILE. Capable of being split asunder.

FISSURE. A crack or open crevice in rocks.

FIXED AIR. Carbonic acid gas.

FLINT. A peculiar form of silex, dispersed either in regular beds or at irregular intervals through chalk.

FLOETZ ROCKS. The name given by Werner, and sometimes employed by the earlier English geologists, to distinguish the comparatively horizontal beds of the Secondary period. The term, being altogether inapplicable in the sense originally intended, is now rarely used.

FLORA. The group of vegetables of all kinds belonging to a natural district, and existing at a given time.

FLUVIATILE. Belonging to a river.

FLUX. A substance added to render certain minerals more fusible.

FORAMINIFERA. The name given to a group of many-chambered shells, generally microscopic, the chambers communicating by a small open orifice (*foramen*).

FORELAND. A promontory or tract of high land jutting into the sea.

FORMATION (in Descriptive Geology). A group of deposits, of whatever kind, referred to a common origin, or belonging to the same period.

FOSSIL. A word originally applied to all substances dug out of theearth, including therefore all minerals, but now limited in its application to the remains of organic beings, whether vegetable or animal, buried beneath the surface.

FOSSILIFEROUS. Containing fossils or organic remains.

FREE-STONE. A stone capable of being readily worked for purposes of construction.

FRESHET. A periodical flood.

FRINGING REEF. A reef or bank of coral of inconsiderable depth, and close to a coast line.

FRITH. A deep and comparatively narrow arm of the sea.

FUCOID. That which resembles a *fucus*, or sea-weed:—fossil remains of fuci are called fucoids.

FULGORITE. Sand-tubes produced by the fusion of loose sand during the passage of lightning through it.

FULLER'S EARTH. A kind of clay containing much water, and used in some parts of the manufacture of cloth.

FUMAROLE. An eruption of smoke.

FUSIBLE. Capable of being fused or melted.

FUSIFORM. Spindle-shaped.

GANOID. A group of fishes having enamelled scales.

GASTEROPODA. A group of shell-bearing animals covered by one valve, and having a fleshy foot attached to the belly.

GAULT. A bluish clay underlying the Chalk and Upper greensand in England.

GEM (in Mineralogy). Any precious stone.

GENUS. A group of species having certain important characters in common.

GEODE. A stone having a hollow in the interior lined with crystals.

GEOGNOSY. A term used in Germany to distinguish the historical sequence of events in the earth's history in contradistinction to GEOLOGY, by which is meant an account of the actual condition of the earth's crust. The distinction, however, is not admitted by English Geologists, and the word is not introduced into our scientific language.

GLACIER. A mass of frozen snow and ice formed in the upper gorges of mountains above the limit of perpetual snow, and proceeding down into the lower parts of valleys or into the sea, in the latter case ultimately breaking off and becoming *ice-bergs*.

GLACIS. A moderately sloping bank or gentle and smooth declivity.

GLANCE (in Mineralogy). A peculiar kind of lustre commonly presented in some sulphurets, as Blende.

GNEISS. The name given to mixtures of quartz, felspar, and mica, in which there is a laminated arrangement of the different ingredients.

GONIOMETER. An instrument, of which there are several varieties, for the purpose of measuring the angles between the plane faces of crystals.

GRANITE. A rock consisting generally of crystals of felspar and mica embedded in a quartzy base.

GRANULAR. Consisting of small grains.

GRAUWACKE or GREYWACKE. The name given by German geologists to some of the older fossiliferous rocks, and generally of a grey colour, sandy composition, and fissile nature.

GRAVEL. An accumulation of small pebbles more or less rounded, occurring with sand and sometimes clay.

GRIT. A coarse-grained sandstone.

GYRATORY. Having a revolving motion.

HABITAT. The natural district to which a species of animals or vegetables is confined in its distribution.

HADE. The dip or inclination of a mineral vein.

HEMI-HEDRAL (in Mineralogy). See § 260.

HEMITROPY (in Mineralogy). See § 287.

HORNBLENDE. An important mineral in the composition of some rocks.

HORNITOS. Small hills in volcanic districts from which hot smoke issues.

HORNSTONE. A variety of quartz found in volcanic districts.

HORSE (in coal mining). A mass of earthy matter intervening between the upper and lower parts of a bed of coal.

HYALINE. Transparent like glass.

HYDROUS. Containing water.

HYDROGRAPHY. The description of the sea, lakes, rivers, and other aqueous portions of the earth's surface.

HYDROLOGY. The science of the distribution and phenomena of water on the earth's surface.

HYGROMETER. An instrument for measuring the degree of moisture of the atmosphere.

HYPOGENE ROCKS. Rocks formed beneath others or which are assumed to have obtained their present aspect underneath the earth's surface.

HYPOTHESIS. A general view founded upon certain known facts of limited range.

ICEBERG. A floating mass of ice, often of great magnitude and always of considerable depth, first produced in cold seas, and conveyed thence into warmer latitudes by marine currents. *Ice-fields* and *Ice-floes* are flat shallow islands of nearly pure ice formed by the freezing of ocean water, but icebergs have generally been detached from glaciers, and are often loaded with gravel, blocks of stone, and earth.

ICHTHYODORULITE. The fossil spine of certain fishes resembling sharks.

ICHTHYOLOGY. The study and description of fishes.

ICHTHYOSAURUS. A marine reptile (fish-lizard), whose remains are very abundant in rocks of the Secondary period.

IGNEOUS ROCKS. Rocks, such as lava, trap, and some others which have been fused by volcanic heat. Granite and other porphyritic rocks are sometimes called crystalline.

IMBRICATED. Covered with scales overlapping each other like tiles on the roof of a house.

IMPERMEABLE. Not admitting the passage of water.

INCRUSTATION. An adherent coating. A crust formed on the surface of any substance.

INDURATED. Hardened.

INFUSORIAL ANIMALCULES. See *Animalcules.* Minute animals found in vegetable infusions, or in stagnant water containing organic matter in a state of decomposition.

INORGANIC. Not produced by vital action.

INVERTEBRATA. Animals not furnished with a back bone.

IRIDESCENCE. Shining with the colours of the rainbow.

ISOCHIMENAL. Having the same mean winter temperature.

ISOCHRONOUS. Occurring at equal times, or equal intervals of time.

ISODYNAMIC. Having the same force.

ISOMERISM. See § 300.

ISOMORPHISM (in Mineralogy). The condition of similar crystalline forms occurring in different chemical combinations.

ISOTHERAL. Having the same mean summer temperature.

ISOTHERMAL. Having the same mean annual temperature.

JOINTS. Natural fissures in rocks, or lines of parting, having definite compass bearings and generally arranged in groups or sets.

KAOLIN. The Chinese name of the fine, pure clay used in the manufacture of porcelain.

KILLAS. A Cornish name for a coarse clayslate, but generally confined to varieties that are not very schistose.

LACUSTRINE. Belonging to a lake.

LAGOON. A salt-water lake, or part of a sea nearly enclosed by a strip of land.

LAMINATED. Arranged in thin plates or *laminæ.*

LANDSLIP. A portion of land that has slid down in consequence of some disturbing or undermining action.

LAPILLI. Small volcanic cinders.

LATERITE. A peculiar rock found in India cut into the form of bricks and used for the same purpose. See p. 544.

LAVA. The melted rock which flows sometimes from a volcano. It consists of a large proportion of felspar, and is often very cellular.

LENTICULAR. Lens-shaped.

LIAS. A provincial name now generally adopted to designate the calcareous clay or clayey limestone occurring between the Upper new red sandstone and the Oolite.

LIGNEOUS. Woody.

LIGNITE. Wood converted into an imperfect kind of coal.

LITHOLOGICAL. A term used to express the stony character of a rock in contradistinction to its zoological or even mineralogical character.

LITTORAL. Belonging to the shore.

LLANOS. The treeless plains of the banks of the Orinoco in South America.

LOAM. A mixture of sand and clay.

LODE. A metalliferous vein.

MACIGNO. An Italian name for a peculiar siliceous sandstone with calcareous grains. See § 791.

MACLE (in Mineralogy). A twin crystal. See § 287.

MALLEABLE. Capable of being beaten out into a thin plate under the hammer.

MAMMALIA. Animals that suckle their young.

MAMMOTH. An extinct and northern species of elephant, the carcase of one individual of which was found buried in icy cliffs on the shores of the Arctic ocean.

MARL. A mixture of clay and lime.

MATRIX. The earthy or stony matter in which a mineral or fossil is embedded.

MECHANICAL ROCKS. Rocks formed by deposition from water.

METAMORPHIC ROCKS. Rocks that have undergone change or metamorphosis since their original formation.

METEORITE. See *Aerolite.*

METEOROLOGY. The science of the phenomena of the atmosphere.

MINERAL VEIN. A crevice in the earth filled with mineral substances, often metalliferous.

MIOCENE. The middle of the three divisions of tertiary rocks, according to Sir C. Lyell.

MIRAGE. An effect of refraction by which distant objects are apparently brought near, or are seen in an inverted position, or of different form from that which truly belongs to them.

MOLASSE. A provincial name for a sandstone associated with marl and conglomerates, found abundantly in the great valley of Switzerland. It belongs to the middle tertiary period.

MOLECULES. The ultimate particles or atoms of bodies. See § 5.

MONSOONS. Periodical winds, occurring chiefly in the Indian ocean. See § 101.

MORAINE. A Swiss term for the débris of rocks brought down into valleys by glaciers.

MULTILOCULAR. Many-chambered.

NEPTUNIAN. A supporter of the theory of aqueous action in the formation of rocks, in opposition to the Vulcanists.

NODULE. A rounded irregular-shaped mass.

NUCLEUS. The solid centre, about which matter is often collected to form solids.

NUMMULITES. A group of foraminiferous shells, some of them of large size and very abundant, occurring in rocks chiefly of the oldest tertiary period.

OASIS. A fertile spot in a desert.

OBLATE. Flattened at the poles.

OOLITE. A limestone composed of rounded particles like the roe of a fish. The name *Oolitic* is applied to a considerable group of deposits in which this limestone occurs.

OPALESCENT. Exhibiting a play of colours like noble opal.

OPALIZED WOOD. Wood penetrated by silica, and acquiring the structure of opal.

OPERCULUM. A kind of lid closing the mouth of univalve shells ; also, the lid or flap covering the gills of fishes.

OPHITE. A rock nearly allied to serpentine.

ORE. The mineral compounds in which metals occur, and from which they are usually obtained.

ORGANIC. Exhibiting organization, or the results of vital force. *Organic remains*, or *fossils*, are the remains of the animals and vegetables of a former state of existence found buried in rocks.

ORYCTOLOGY. A term now entirely disused, meaning an account of all bodies whether organic or inorganic, found buried in the earth.

OSSEOUS. Bony: *Osseous breccia* is a conglomerate made up of bones cemented together by lime, and mixed with earthy matter.

OUTCROP. The line at which a stratum first shows itself at the surface in inclined deposits.

OUTLIER. A portion of a stratum detached from the principal mass. (See figs. 113—119.)

OXIDATION. The combination of a substance with oxygen—the film generally produced on the surface of metals and many earths by this process is called an *oxide*. In some cases, as in that of iron, it is called *rust*.

PACHYDERMATA. A group of animals so called from the thickness of their skin. The elephant and pig are well known examples.

PALÆONTOLOGY. The science which treats of fossil organic remains: it is the zoology and botany of the ancient conditions of the earth.

PALÆOTHERIUM. A genus of Pachydermata, allied to the Tapir. (See *Anoplotherium.*)

PAMPAS. Treeless plains of Patagonia in South America. (§ 64.)

PAPER COAL. A thinly laminated lignite, or bituminous shale, splitting into leaves.

PARTING (in mining). The name given to a thin seam between two beds.

PEAT. A vegetable accumulation produced in moist situations, and presented in a spongy mass.

PEGMATITE. A granite in which the three component minerals form distinct masses, united and cemented together.

PELAGIAN. Belonging to the sea.

PEPERINO. An Italian name for a particular kind of volcanic rock, formed by the cementing together of volcanic sand and ashes.

PERCOLATION. The filtering through of water.

PETRIFACTION. The act of turning into stone. (See § 298.)

PETROLEUM. Mineral pitch.

PHÆNOGAMOUS, or PHANEROGAMIC PLANTS. Those in which the reproductive organs are apparent.

PHYSICAL. Literally *natural*, but used in scientific language in treating of the higher and wider views of various departments with reference to the whole external world, and not to mere human objects. Thus *Physical Geography* includes the description of all the natural phenomena of the globe.—*Physical Geology*, that part of Geology in which the history of all Nature, from all time, is discussed. So also by PHYSICS we understand the department of science which treats of the various properties of natural bodies, the laws of their motion, and the results of their mutual action in a mechanical sense.

PHYTOLOGY. The department of Natural History which relates to plants. Botany.

PIPE CLAY. A plastic clay used in making pipes.

PISIFORM. Pea-shaped.

PISOLITE. A stone made up of rounded concretions like peas. The word *pisolitic* is used to express an approximation to this structure.

PIT-COAL. The name often given to common coal, from its being dug out of pits.

PLACOID. A group of fishes, so called from the structure of their scales.

PLASTIC. Capable of being moulded into form. Thus, *plastic clay* is so called from its use in pottery. The *Plastic clay formation* is the lower part of the older Tertiary series, containing in some places clay used in pottery.

PLATEAU (in Physical Geography). A plain or expanse of land considerably above the level of the ocean.

PLESIOSAURUS. An extinct genus of reptiles. (See § 846.)

PLICATED. Arranged in folds or contortions.

PLIOCENE, OLDER AND NEWER. The upper part of the Tertiary series, so called by Sir C. Lyell from the preponderance of recent shells in them.

PLUMBAGO (Black lead). The name commonly given to *graphite*, a form of carbon.

PLUTONIC ROCKS. Rocks supposed to be due to igneous action at great depths below the earth's surface, have been thus named by older geologists. The igneous action is not manifest in such rocks, but presumed, as in the case of granite.

PŒCILITIC. From a Greek word signifying *variegated*—the name given to the upper part of the New red sandstone series of England.

POLAR FORCES. (See § 29.)

POLYPARIA. A group of animals of which the *coral animal* is a well known example.

POLYTHALAMOUS. Many chambered.

PORPHYRY. A name originally given to a red rock with small crystals of felspar, found in Egypt, and so called from its usually red colour; although our present purple (also derived from the same word), is very different. The word is now used to denote any rock having crystals, embedded in a base of other mineral composition. Thus granite is a porphyritic rock, having crystals of felspar and mica embedded in a quartz base.

POZZUOLANA. Volcanic ashes used in Italian buildings instead of mortar, and answering the purpose of Roman cement. It is so called because shipped from Puzzuoli.

PRAIRIES. The level plains of some of the great river valleys of North America, are thus denominated.

PRECIPITATE. The deposit obtained when substances that have been dissolved in a fluid are thrown down by further chemical combination, and in consequence of new affinities produced.

PRIMARY, or PRIMITIVE. This name is commonly applied to the rocks which underlie those that are manifestly of mechanical origin and contain fossils. The use of the term, however, involves an hypothesis which is by no means to be admitted namely, that such unfossiliferous and crystalline rocks were earlier formed than any deposits containing organic remains. It is desirable that no such expressions should be employed; and Sir C. Lyell has suggested the word *Hypogene* as adapted to replace Primary. Perhaps merely descriptive names, as *Crystalline*, are yet more satisfactory. Almost all these rocks are *Metamorphic.*

PTERODACTYL. A remarkable genus of reptiles adapted for flight: its remains have been found in a fossil state throughout the Secondary rocks.

PUDDING STONE. The name often given to coarse conglomerates in which the fragments or pebbles are rounded.

PUMICE. Volcanic ashes.

PYRITES. A name given to the combinations of certain metals with sulphur. Iron and copper pyrites are the most common; the former is often found in chalk, slate, and other stratified rocks, the latter only in mineral veins.

PYROMETER. An instrument for measuring intense heat.

QUA-QUA-VERSAL. The dip of beds in every direction from an elevated central point. The beds on the flanks of a volcanic cone dip in this way.

QUARTZ. The common form of silica; rock-crystal and flint are examples.

QUARTZITE. A rock composed of quartz grains, passing into compact quartz.

RADIATA. A division of the animal kingdom so called because the body is frequently presented in a radiated form like the common star fish.

RADIATION (in Chemistry). The mode in which heat is thrown out into space from the surface of any substance.

RAG. A stone of coarse texture; the name is given indifferently to aqueous and igneous rocks.

RAKE VEIN (in mining). A group of vertical veins.

RAVINE. A deep, hollow, narrow excavation.

RECENT. The name given in Geology to the period immediately past or still in progress; the limit of existence of some races of animals and vegetables is generally taken as that of the recent period.

RED MARL. A name for the New red sandstone.

REFRACTION. The bending aside of light when it passes from one transparent substance into another of different density. *Double Refraction* is the separation into two rays that occurs when light enters certain crystals, as Iceland spar.

RETICULATED. A structure of crossed fibres, like a net, is said to be reticulated.

ROCK (in Geology). Any mass of mineral matter of considerable or indefinite ex-

tent and nearly uniform character, is called in geological language a rock, without regard to its hardness or compactness: thus, loose sand and clay, as well as sandstone and limestone, are spoken of under this name.

ROCK SALT. Common salt occurring in a crystalline state in rocks.

ROE-STONE. The name sometimes given to *Oolite.*

ROTHE-TODTE-LIEGENDE. The German synonym for the lower part of the Magnesian limestone, or Permian series.

RUBBLE. A term applied by quarry-men to the fragmentary and decomposed parts of stone generally surmounting each bed.

RUMINANTIA. An important group of quadrupeds including those which chew the cud, as the ox, deer, &c.

SACCHAROID. Having the texture of loaf sugar.

SALIFEROUS SYSTEM. The New red sandstone system, so called from the salt with which it is associated in parts of England.

SALSES. Eruptions of mud from small orifices, generally in volcanic districts.

SAURIAN (Reptilian). Any animal of the lizard tribe, and many extinct reptiles only distantly allied to these.

SAVANNAHS. The low plains of North America, generally covered with wood.

SCAGLIA. An Italian rock, contemporaneous with our chalk.

SCARPED. Having a steep face.

SCHIST. A name often used as synonymous with slate, but more commonly and very conveniently limited to those rocks which do not admit of indefinite splitting, like slate, but are only capable of a less perfect separation into layers or laminæ. Of this kind are gneiss, mica-schist, &c., often more or less crystalline.

SCORIÆ. The name given to volcanic ashes. The word means any kind of cinders, but its scientific use is thus limited.

SEAMS. A name sometimes given to any thin beds, but more usually applied to thin layers separating two strata of greater magnitude.

SECONDARY STRATA. An extensive and important series of stratified rocks, having certain characters in common distinguishing them from the overlying rocks called "Tertiary," and the underlying group known as the "Palæozoic."

SELENITE. A name often given to crystalline sulphate of lime.

SEPTARIA. Flattened nodules often found in clay, and consisting chiefly of argillaceous limestone, traversed by numerous cracks proceeding from the centre, and often filled with calc spar.

SEPTUM. A partition; the plates separating the chambers in the Nautilus and other allied genera are called *septa.*

SERPENTINE. A rock generally more or less crystalline, and often of green and variegated colour; it is abundant in the Alps, and is found also in Cornwall.

SHALE. See *Schist* and *Slate.* An indurated clay, less fissile than schist, but splitting with tolerable facility in plates parallel to each other, and to the original planes of bedding.

SHANKLIN SAND. A name given to the Lower green-sand from its being found at Shanklin, in the Isle of Wight.

SHELL MARL. A deposit of clay, peat, and silt, mixed with shells, which collects at the bottom of fresh water lakes.

SHINGLE. The loose rounded water-worn fragments of stone or gravel found on the sea shore, or where the sea has once been.

SHOOT (in mining). A vein parallel to the stratification.

SILEX, SILICA. The name given by Mineralogists to a pure earth, more commonly spoken of as *flint*, and, when crystallized, called rock crystal. (See § 359.) *Siliceous* means flinty, and *silicified* a substance mineralised by siliceous earth. *Siliceous sinter* is a siliceous deposit from springs.

SILT. The name usually given to the muddy deposit found at the bottom of running streams. Rivers and creeks are often said to be *silted up* when this deposit accumulates at their mouths.

SILURIAN. The name given by Sir R. Murchison to an important series of fossiliferous rocks well developed in, and first described from, a district in Wales and Shropshire formerly inhabited by the *Siluri*, a tribe of Ancient Britons.

SILVAS. The wooded plains of the Amazons River in South America.

SIMPLE MINERALS. Minerals that admit of definite description as consisting of definite chemical compounds occurring in nature.

SIMPLE ROCKS. Rocks containing some very predominant mineral and developed to a great extent in nature. Thus limestone, sandstone, clay, granite, &c., are simple rocks.

SINTER. A rock precipitated from mineral water. Calcareous and siliceous sinters are those only that are generally described.

SIPHUNCLE. A small tube passing through an orifice in the septum of a chambered shell.

SLATE. The most perfectly fissile form in which clay exists in nature. See *Schist* and *Shale*, where the less perfectly cleaving rocks of this kind are described.

SLICKENSIDES. The smooth striated surface of a fault ; also one of the ores of lead found in Derbyshire.

SLIDE. A miner's name for a small fault.

SOIL. The name given to the disintegrated and decomposed rock at the surface of the earth when this has become mixed with carbon and other substances so as to enable plants to grow and obtain their required mineral constituents.

SOLFATARA. A volcanic vent from which sulphur and sulphurous, watery, and acid vapours and gases are emitted.

SOLID ANGLE. The inclination of three or more planes meeting in a point.

SPAR. A name given to many crystalline minerals which usually afford clean and ready fracture.

SPECIES (in Natural History). This term, the true application of which is most important in Natural History, is understood to mean in the higher forms of animal existence a group of all the individuals which, under ordinary conditions and in a natural state, breed together and produce like individuals. When offspring is obtained from a male and female of distinct species (which is not usual), this is either absolutely barren, or at least becomes barren in one or two generations, so that no new form or species is thus perpetuated. The differences of specific

character are apparently preserved in almost all details of structure in these cases but the term species must often be applied doubtfully and hypothetically in animals of lower organisation, in plants, and above all in minerals.

SPHEROID. Having a shape nearly resembling that of a sphere or globe.

SPRINGS OF WATER. See § 1049.

SQUALOID. Resembling a shark.

STALACTITE AND STALAGMITE. Concretions of carbonate of lime and sometimes of other minerals, as quartz or even malachite, deposited by water dropping from the roof of a cavern or other vacant space. When the mineral is deposited in columns pendant from the roof of the cavity the name *Stalactite* is given. When the columns or heaps rise from the floor after the water has dropped they are said to be *Stalagmites*.

STANNIFEROUS. Containing tin.

STEPPE (in Physical Geography). A low plain.

STOCK-WORK. A vein of very great magnitude, requiring to be worked with special reference to this unusual condition.

STRATIFICATION. The condition of rocks or accumulated minerals deposited in layers, beds, or *strata*. A single bed is called a *stratum*. A large proportion of the masses constituting the earth's crust are thus arranged or *stratified*, and the planes of stratification are generally parallel to each other, though often much removed from their original condition of horizontality.

STREAM-WORK. A place where metalliferous ores are obtained and worked by the mechanical use of water in separating the ore from gravel with which it is found.

STRIKE. The line of bearing of strata, or the direction of any horizontal line on a stratum.

STUFA. A jet of steam issuing from fissures in volcanic regions at a temperature often much above the boiling point of water.

STRUCTURE. A term often used technically in Geology and Mineralogy to denote the condition in which the component parts are arranged.

SUB-APENNINE BEDS. The name of a deposit found in a low chain of hills at the foot of the Apennines in Italy.

SUBLIMATION. The deposit of a solid from a state of vapour.

SUBSIDENCE. The act of sinking, often traceable over extensive areas and connected with great geological changes.

SUBSOIL. The decomposed rock often underlying vegetable soils, and not exposed at the surface except by denudation or deep ploughing.

SULCATED. Furrowed

SUPERPOSITION. An expression very commonly employed by Geologists to describe the order of arrangement when one bed or stratum reposes upon another. See *Conformable* and *Unconformable superposition.*

SUPRA-CRETACEOUS. A term applied by Sir H. de la Beche to the rocks overlying the chalk. The term Tertiary is now universally adopted for this group.

SURTURBRAND. A name sometimes given to varieties of lignite.

SYENITE. The granite of the quarries of Syene in Egypt. It is usual to call by

this name any combination of quartz, felspar and hornblende ; but the quartz is sometimes absent and sometimes accompanied by mica.

SYNCHRONOUS. Occurring at the same time. Contemporaneous.

SYNCLINAL AXIS. The line of depression between two anticlinal axes. See § 611.

TABLE LAND (in Physical Geography). Land elevated much above the level of the sea and generally offering no considerable irregularities of surface.

TALUS. The accumulation at the foot of a steep rock, produced by fragments broken off, fallen down, and formed into a sloping heap.

TERMINOLOGY. The technical classification of a science, and the terms used in it in a technical or special sense.

TERTIARY STRATA. The series of sedimentary rocks overlying the chalk, or other representative of the Secondary period, and extending thence to the rocks of the Recent period.

TESTACEA. Molluscous or soft animals having a shelly covering.

THERMAL. Hot. *Thermal Springs* are springs whose temperature is above the mean annual temperature of the place where they break out.

THERMOMETER. An instrument for measuring differences of temperature by comparing them with the expansion and contraction of a fluid having a graduated scale attached to it.

THINNING OUT of strata. When a stratum gradually diminishes in thickness as it is traced in any particular direction, and ultimately disappears, it is said to thin out.

TOAD-STONE. The name given by miners to beds of basalt, occurring in Derbyshire. It is probably derived from the German *Todt-stein*, or dead-stone, as being without the ores found in the neighbouring limestone.

TORNADO. A violent storm or hurricane.

TRANSITION. The name formerly given to certain rocks, now called *Palæozoic*, under the impression that they afford a passage from the crystalline state of gneis, mica schist, clay-slate, &c., to what was considered the more mechanical condition of Newer or Secondary rocks. Since, however, it appears that such transition belongs to no particular geological period, but occurs in all, the term has ceased to be applicable and has fallen into disuse.

TRADE-WINDS. Winds, chiefly from the east, blowing constantly in particular latitudes and useful in navigation. See § 99.

TRAP. Crystalline rocks, composed chiefly of felspar, augite, and hornblende, combined in many ways, and exhibiting great varieties of aspect, are frequently called by this name. The word is derived from the Swedish *trappa*, a stair or step, because such rocks are often found in large tabular masses, rising one above another in steps. Trap, or Trappean-rock, is supposed to have been lava formerly ejected from fissures or craters, and often poured out under water. *Basalt* is the most common synonym for trap rock.

TRAVERTIN. A white concretionary stone, usually hard and semi-crystalline, deposited by water containing lime in solution, and very abundant in some parts of Italy.

TRIAS. The name given on the continent to the beds of the New red sandstone series.

TRILOBITE. A common fossil in the Dudley limestone, so named from the characteristic species having the body divided into three lobes. Trilobites are the remains of a remarkable extinct family of Crustaceans, of which the crab, lobster, &c., are modern representatives.

TRIPOLI. A powdery, siliceous rock, used in polishing metals and stones, and derived from the siliceous cases of infusorial animalcules.

TRUNCATED. Cut off or shortened. A crystal is said to be truncated when a solid angle or edge is removed symmetrically.

TROUGH (in Geology). A basin-shaped or oblong depression.

TUBBING, METAL (in mining). The cast-iron famework fitted to a shaft in order to keep out springs of water from the works.

TUFA, TUFF. An Italian name for a variety of volcanic rock of earthy texture, and made up chiefly, or entirely, of fragments of volcanic ashes.

TURBINATED. Shells which have a spiral or screw-like structure are thus named.

TURRILITE. An extinct genus of chambered shells, resembling an Ammonite wound into a turbinated form.

TYFOON, or TYPHOON. A violent periodical hurricane occurring in the China Seas.

TYPE (in Natural History). A representative form.

UNCONFORMABLE SUPERPOSITION (in stratification). The condition of strata when one has been deposited horizontally upon the upturned edges of those immediately below.

UNDERCLIFF. The name applied to a cliff when the upper part has fallen down along a considerable line of coast, and forms a subordinate terrace between the sea and the original shore.

UNDERCLAY. The fine tenacious and tolerably pure clay, containing frequently roots of Stigmaria, and very often found below beds of coal in the coal-measures.

UNDERLAY, or UNDERLIE. The dip or inclination of a mineral vein.

UNIVALVE. An animal provided with a shell in one piece.

UNSTRATIFIED. Rocks have sometimes been divided into two principal groups, Stratified and Unstratified, and these have been assumed as synonymous with Aqueous and Igneous. Granite and many of the rocks usually regarded as of igneous origin, are, however, sometimes found in beds or strata.

VEINS, MINERAL. Crevices in rocks filled up with mineral substances often crystalline.

VEINSTONE. The earthy minerals occupying veins when these are associated with metalliferous ores.

VERTEBRATA, or Vertebrated Animals. A large and most important division of the animal kingdom, including all those animals provided with a back bone. Each separate bone of the back is called a *vertebra*.

VERTEX. The summit or upper part of a solid.

VITREOUS. Glassy. Used in Mineralogy to designate a peculiar lustre.

VOLCANO. A mountain or hill of conical shape, having at or near the summit a cup-shaped depression called the "crater." From this proceed vapours of sulphurous

and acid gases with jets of steam, and from time to time ashes are thrown up high into the air: or currents of melted rock or lava burst forth and pour down the sides. *Volcanic bombs* are detached masses ejected into the air, and assuming a pear shape as they fall. *Volcanic foci* are subterranean centres of igneous action.

VULCANIST. A supporter of the theory of igneous action in the formation of rocks as opposed to the Neptunians, who believed in aqueous action only. A term of reproach belonging now only to the history of Geology.

WACKÉ. A barbarous name, formerly much employed by German geologists, and thence introduced into English descriptions of the same date. It is regarded as a soft and earthy basalt, but has been used in other senses and rather indefinitely.

WARP. The deposit of muddy waters artificially introduced into low lands.

WASTE (in mining). That part of a coal-mine out of the course of the principal ventilation.

WATER-SHED. The line between two river basins. The water-shed is not necessarily a mountain-chain, and in some rare instances it is broken by a water communication connecting two great river systems.

WEALDEN. The name given to an important fresh-water formation, occurring between the Cretaceous and Oolitic rocks, chiefly in the Wealds of Kent and Sussex.

WEATHERING. The wearing away of rocks consequent on atmospheric exposure.

WHET-STONE. A very hard and fine-grained slate containing much quartz.

WHIN-STONE. A provincial term applied to some trap rocks.

WIND-ROSE. An account of the mean pressure of the air under different winds. See § 89.

ZAFFRE. The impure oxide of cobalt, which, when melted with silica and potash and reduced to powder, becomes powder-blue.

ZECHSTEIN. The German synonym for our magnesian limestone.

ZEOLITE. A group of minerals which swell and boil up when exposed to the blowpipe flame. See § 417.

ZOOPHYTE. The term applied to some animals of low organisation, which, during the greater part of their lives, are attatched to some foreign substance, and are incapable of locomotion.

ALPHABETICAL INDEX.

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THE END.

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